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ANALYSIS OF AIR CUSHION VEHICLES IN ARMY LOGISTIC OVER THE SHORE (LOTS) OPERATIONS (U)

VOLUME 2

Task 9R99-01-005-07

Contract DA 44-177-TC-723

March 1962

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TECHNICAL REPORT

ANALYSIS OF AIR CUSHION VEHICLES IN

ARMY LOGISTIC OVER THE SHORE (LOTS) OPERATIONS **(U)**

VOLUME 2. TECHNICAL REPORT **(U)**

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(U) SUMMARY

Volume II contains the details of the technical work of the operations analysis conducted by the Aeronutronic Division of the Ford Motor Company of the air cushion vehicle (ACV) in the Army Logistics-Over-The-Shore (LOTS) operation.

A critical examination of the LOTS mission is accomplished to determine those operational and environmental factors that critically influence ACV lighterage design. Available technical theory and data are applied in determining practical ACV design characteristics for lighterage to be used within the limiting operational and environmental factors thus established.

A conclusion has been reached that the LOTS mission is unduly restricted by the utilization of low speed lighterage. The acquisition of high speed amphibious lighters within the Army inventory will greatly increase the distances to which LOTS lighterage operations can be extended economically within the 1965-1970 period. This extension of the practical operational radii of lighterage will greatly expand the patterns that can be developed for the dispersal of shipping as a means of passive defense against the threat of mass destruction weapons. It will add greatly to the flexibility and effectiveness of theater lighterage operations.

An ACV lighter designed to operate at a clearance height of 3 feet is considered capable of safetly surmounting and negotiating the waves and surf generally associated with sea conditions in which ship unloading operations can be continued. The 3 foot operating height provides sufficient terrain clearance for a significant improvement in existing off-road mobility for the inland portion of the mission.

The overland mobility of ACV amphibious lighterage is unaffected by deteriorated route surface conditions that appreciably slow or completely halt the movement of ground contact vehicles.

A minimum cargo space of 11 feet by 35 feet is required in the 10 ton to 15 ton capacity lighters to provide sufficient space to load either a high percentage of the Army vehicles falling within these weight limitations, or to load to capacity with military dry cargo. These cargo compartment dimensions appear compatible with over-all vehicle design characteristics.

Limiting plan dimensions for loading the lighters on hatches of MSTS and commercial cargo ships generally constrain the vehicle size to 35 feet by 70 feet. Within this restraint, transhipment of a given

cargo transfer productivity in ACV lighterage for use in the currently planned short radius LOTS mission poses no greater problem than does the transhipment of an equal productivity in wheeled amphibious lighters. At operating distances greater than those currently planned for the LOTS lighterage mission, which is considered to be highly desirable for the 1965-1970 time period, a greater productive capacity in ACV lighterage can be transhipped in an average grouping of MSTS and commercial cargo ships.

ACV lighterage, at this point in design development, are considered to offer an appreciable potential for self deployment over extended over-water distances on the order of 1,000 to 1,500 nautical miles.

Application of flexible skirts to the ACV design is highly effective in reducing the power requirements and produces an ACV amphibious lighter economically competitive with wheeled amphibians. The state of development of flexible skirt design and fabrication techniques has not progressed to the point where selective differentiation can be made between the full and partial skirt in the ACV amphibious lighter application. A 10 ton capacity partially skirted ACV lighter and a 15 ton capacity fully skirted ACV lighter are recommended for continuing analysis and further comparative evaluation in determining the most desirable configuration of a first generation ACV lighter. Experimental development and tests of ACV flexible skirts, currently being conducted, give promise of furnishing the technical information of the operation practicalities and the optimum lengths of peripheral skirts to be used in ACV lighterage design.

ACV lighters are found to be economically competitive with wheeled amphibians at the operating radii of 3 miles overwater and 6 miles over land currently used as general planning factors for the LOTS lighterage mission. As operational radii are extended beyond these average distances, the ACV lighter shows a progressively increasing economic advantage over these forms of lighterage.

Design, construction and test of a first generation ACV lighter in realistic LOTS operations appears justifiable and is recommended for an early date. Such tests will provide for the more precise definition of the design and operational factors which do not lend themselves to analyses and serve as a basis for refinement of the criteria developed herein.

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(U) SECTION I

INTRODUCTION

A. STUDY AUTHORITY

The Operations Analysis contained in this report of Air-cushion Vehicles (ACV) in Army Logistics Over the Shore (LOTS) operations was conducted at the request of the U.S. Army Transportation Research Command (TRECOM). The study commenced 15 March 1961 upon issuance of Contract DA 44-177-TC-723 to the Aeronutronic Division, Ford Motor Company. Responsibility for conducting the study was given to the Air-cushion Vehicle Department of Aeronutronic Division, Mr. M.F. Southcote, Manager. Lt. Col. A.M. Steinkrauss of U.S. Army TRECOM served as contracting officer and Mr. William E. Sickles as the Army's technical project leader. Aeronutronic effort on this program was lead by Mr. S. Bresin, with significant contributions provided by Mr. G. Fulton, Major General S.S. Jack (U.S.M.C. Ret.) and Mr. W.W. Millar. The Army's project monitoring group, chairmanned by Lt. Col. J. Wright (TRECOM), provided guidance and necessary study information. The analysis was concluded on 30 November 1961 with issuance of this final report to U.S. Army TRECOM for approval.

B. STUDY OBJECTIVES

Three fundamental objectives were pursued during the course of study. These objectives were:

1. A definition of the desirable characteristics of air-cushion vehicles for use as lighterage in Army LOTS operations. The detail of definition to be consistent with the degree of preciseness permitted by:

   (a) the availability of quantified LOTS operational data

(b) the available data on costs and characteristics of complementary equipments used in LOTS operations.

(c) the availability of quantified environmental data

(d) the available air cushion vehicle technology

(e) the allocation of time and funds for the study

2. A development of logistic supply system costs affected by the LOTS operations. The developed costs reflect LOTS operations conducted with selected wheeled amphibians, a helicopter and those conducted with ACV lighterage. These costs are expressed in terms of dollars, manpower, and fuel and measured against the effectiveness of cargo delivery rate, timely reaction to military cargo requirements, and increased capability and flexibility in currently planned operations.

Ideally, it would be desirable to provide comparison of the ACV with other forms of amphibious lighterage currently under research, such as amphibious hydrofoil and amphibious hydroplane craft. However, lack of available data on these craft precluded meaningful comparison at this time.

3. An estimate of possible improvements in LOTS operational efficiency and capabilities. The possible improvements include those resulting from changes to operational procedures and changes to existing equipment as well as those resulting from the introduction of ACV amphibious lighterage.

C STUDY APPROACH

In assessing the military worth of the ACV amphibious lighter in the LOTS application, it was deemed necessary to establish the many facets of the operation, the technical characteristics of the lighterage employed and the Army's investment objectives. The study, therefore, seeks to uncover the significance of applicable factors in the LOTS operation, the effects upon the operation resulting from varying the design parameters of the lighterage employed, and the influences that these variables have upon the military investment in the operation. Mathematical analyses were employed to delineate the relationship where quantification permitted. Unquantifiable factors affecting the relationship have been discussed objectively to disclose their influence on the LOTS operation and upon the design characteristics of applicable ACV amphibious lighterage.

A first step in the analysis was to obtain a quantitative definition of the LOTS operation. This became a difficult task since apparently there is no accepted set of parameters which fully describe and constrain the LOTS mission in its application to specific military operations.

Visits to Army and other governmental agencies were employed to uncover the most widely accepted and salient factors of LOTS operational doctrine and procedures. The information thus gained, together with the generalized LOTS operational factors contained in Reference 1 (FM 101-10), were used to develop the contractor's understanding of the LOTS concept as it is set forth in the next section of this report; and to test the reasonableness of operational parameters used in the quantitative analysis. This interpretation of LOTS operations for the 1965 to 1970 time period was confirmed when a subsequent comparison with the concepts developed in Reference 2 revealed no significant differences.

Constraining parameters of the LOTS operation, as formulated, have been extended when it was considered that lighterage performance offered a possibility of broadening the base and increasing the flexibility of the operation. In such cases, corresponding changes in system costs have been ascertained as accurately as available data permit in order to provide information upon which to assess the military worth of ACV lighterage configurations.

Within the overall limitations of the study, every effort has been made to develop attainable design criteria for an ACV amphibious lighter that will satisfy fully the operational requirements of the LOTS mission with minimum total investment of force, materials and monies. An exploration was made of such possibilities as presented themselves for broadening the scope and increasing the flexibility of military accomplishment at an equivalent or an acceptable increase in military investment.

It must be recognized that a study of this nature cannot be accomplished sequentially. All significant factors must be dealt with simultaneously as schematically indicated on Figure I-1, in order that the interrelated considerations be properly reflected in the vehicle concept.

The objectives of the operation establish the measures of effectiveness against which the vehicle's worth is measured. For example, LOTS operations for resupply of Army units in the field have as their

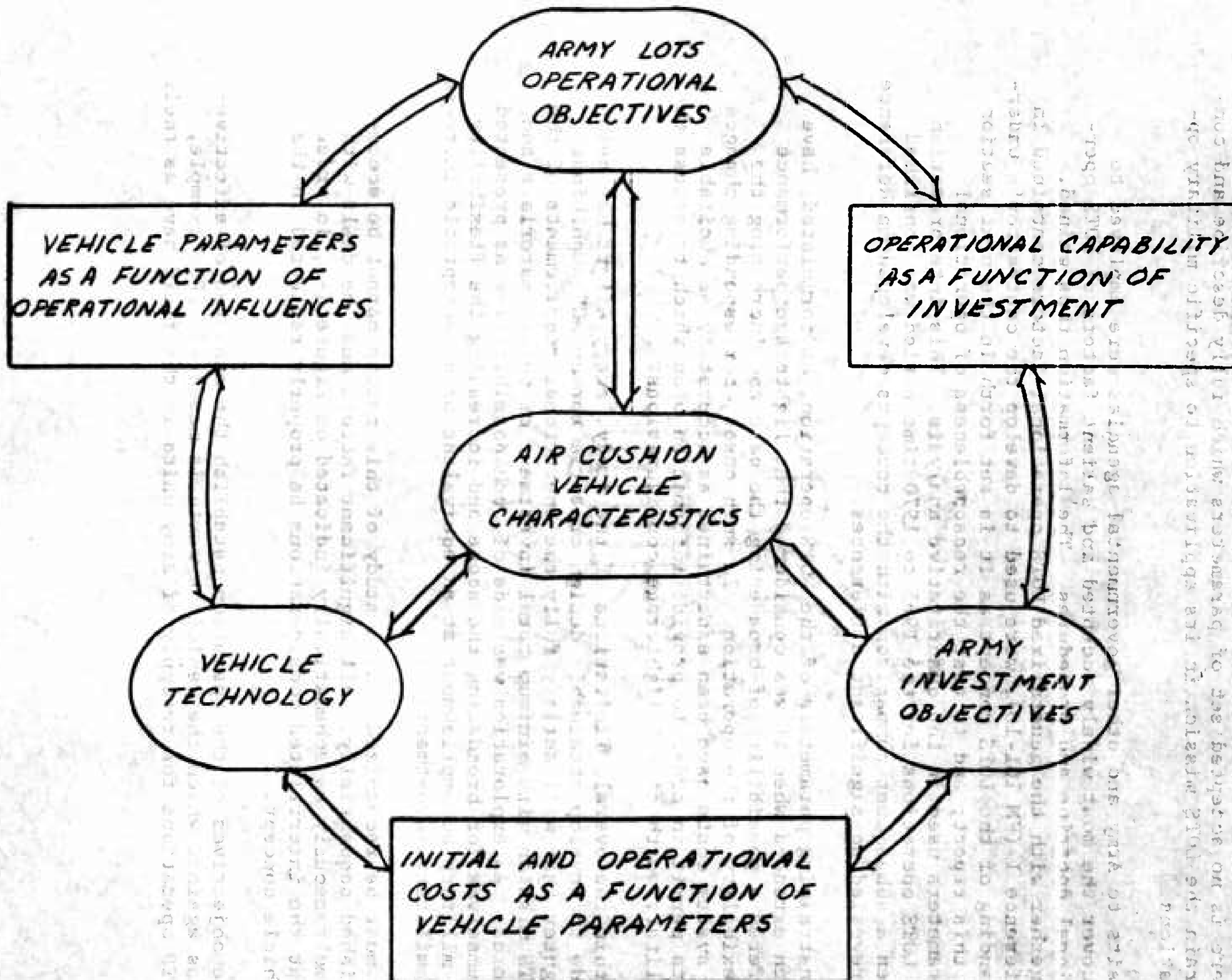


Figure I-1. LOTS Operation and Air Cushion Vehicle Interactions.

fundamental military objective the provision of a given level of daily supply per Army unit on a continuous basis. Additionally, it is desired that the required amount of supplies be provided as economically as possible and in a timely fashion. These fundamental objectives dictate that the lighterage vehicle selected for the LOTS operation should result in attaining the maximum operational economy for the system within the constraints imposed by other system factors.

The vehicle's technical characteristics and capabilities were reflected in terms of the fundamental LOTS operation objectives and other significant LOTS operation factors in order to arrive at the most appropriate vehicle compromises. Unfortunately, not all system factors are quantifiable as was previously indicated. Two of the most notable and significant factors influencing the vehicle's desired characteristics are obstruction and wave heights. These natural phenomena are completely random in nature and it is not possible within the realm of practicality to adequately quantify all possible terrain and sea conditions. Available statistical data and probability analysis were used in such instances to provide a basis for objective generalizations which lead to logical assumptions for operational and vehicle characteristic criteria. The resulting criteria are then utilized to provide vehicle design objectives.

D. REPORT ORGANIZATION

The final report covering operational analysis of air cushion vehicles in LOTS operations has been prepared in two volumes.

Volume ONE of the final report presents a summary of operational and technical considerations, together with a comprehensive summary of conclusions and recommendations derived from the analysis.

Volume TWO of the final report contains the details of the technical work. This volume is organized to present:

(1) An understanding of current LOTS operations.

(2) A development of factors which lead to extensions of currently planned LOTS operations.

(3) A development of LOTS operation and environment factors which influence or constrain the ACV characteristics.

(4) A development of the technical characteristics and costs of air cushion vehicles.

(5) A determination of the sensitivity of assumptions employed in the analysis.

(6) A listing of competing and complementary vehicle characteristics.

(7) A comparison of the air cushion vehicle with competing and complementary vehicles.

(8) An appraisal of logistic supply system costs which are influenced by the lighterage employed in LOTS operation.

A suggested list of design characteristics for a first generation air cushion vehicle suitable to LOTS operations is also presented. This list of desirable air cushion vehicle characteristics reflects the significant operational factors uncovered during the course of the study.

E. REPORT CLASSIFICATION

Sections, II, III A, III B, and VI of this report contain portions classified "Confidential", consistent with the classification of extracted reference material used in these sections. While specific reference is made to a document classified "Secret" (Reference 2) the material obtained from this report was extracted from unclassified sections.

(c) SECTION II

THE LOGISTICS OVER THE SHORE (LOTS) MISSION (U)

A.(U) LOTS MISSION DEFINITION (U)

Logistics over the shore (LOTS) operations are employed for the resupply of Army units in the field. They are defined as the transfer of cargo and men from ships to lighters for movement over the shoreline to inland transfer points.

B.(C) LOTS CONCEPT (U)

The advent of atomic warfare brought on early realization that many of the tactics of World War II were no longer tenable. The very concentrations of military forces that led to past successes would only serve to increase the vulnerability of the operation to overwhelming defeat in a nuclear environment through the enemy use of mass destruction weapons. Major attention has been given to means of eliminating large concentrations of men and material, except as required in direct contact with the enemy. The wide dispersal of forces dictated by the requirements of passive nuclear defense has increased the requirements for high speed mobility to permit rapid forming of the tactical concentrations required to overwhelm enemy centers of resistance. These requirements for dispersal and mobility of combat forces apply equally to the combat support operations within the theater of operations.

In recognizing the requirement for dispersed unloading of resupply shipping, a concept of Logistics Over The Shore (LOTS) operation has been developed. In this concept use of major ports will be largely eliminated, either by nuclear destruction or because of the nuclear and conventional warhead guided missile threats imposed on the heavy concentrations of shipping and port facilities associated

with such operations. In lieu thereof, resupply shipping will be unloaded from ships lying at dispersed sites off shore. Cargo will be lightered by amphibious lighters over the beach and far enough inland to permit discharge at widely dispersed transfer and storage sites. The only cargo that will be unloaded at the shore line, or in the immediate vicinity of the beach, will be vehicles that are capable of roll-off discharge and immediate dispersal under their own power to assembly areas remote from the points of beach crossing.

Long range development and procurement planning for equipment and development of military organizational structure requires an assumption of mission criteria that are plausible under what can be termed average operational conditions. With the certainty that such "average" conditions will seldom be realized in actual operations, the basic assumptions may be used nevertheless as an analytical base from which planning for an actual operation can take departure.

The criteria currently in use for the LOTS mission assume that an unloading site handling 2 cargo ships will support the dry tonnage requirements of a theater division slice; i.e., the discharge of 1440 short tons of dry cargo per day. Current planning estimates that ships will lie an average of 3 miles off shore and will work 5 hatches each, an average of 20 hours per day, with an average hatch rate of 7.2 short tons per hour. Ship unloading sites will be dispersed with at least 5 miles separation between sites. Sites will be shifted in order to reduce periods of fixed geographical location to less than the enemy reaction time in delivering atomic or conventional warheads on targets of opportunity with guided and homing weapons.

The existing concepts further establish that lighterage serving each unloading site will work a corresponding 20 hour day to discharge the 1440 tons of dry cargo over the beach to dispersed cargo transfer or storage sites located an average distance of 6 miles inland. Planning factor cargo unloading rates for lighters are currently established at 14.4 short tons per hour.

Basic organization of combat support units employed in the LOTS operation have been developed within the frame-work of the criteria cited above. The ship and shore platoons of the Transportation Terminal Service Company are currently organized to work 5 cargo hatches per ship at corresponding cargo transfer rates of 720 short tons per ship per 20 hour working day. Amphibious lighterage organizations are predicated upon equipment characteristics and similar operational

factors to develop the required productivity. Thus, a Transportation Amphibious Company (light) (TOE 55-138T) or a Transportation Amphibious Company (medium) (TOE 55-139T) will transport 1080 short tons of cargo per day when operated in the typical LOTS mission as set forth previously. Either of these standard lighterage organizations, when augmented by a platoon of amphibious lighters from the Transportation Amphibious Company (heavy) (TOE 55-140T), has an additional daily productivity of 360 short tons of vehicular, heavy lift, or out-sized cargo. The combination can provide transfer of the total 1440 short tons of cargo per day assumed for the LOTS mission at a single unloading site.

The LOTS operations are considered to be continuous throughout the period of Military Operations. They may be initiated even before hostilities commence as a precautionary dispersal of the port operation in support of forces predeployed to a probable theater of operations. They may begin within a matter of hours of the launching of an amphibious assault and continue concurrently with the unloading of the landing force and the follow-on build up of combat forces. In the latter cases, the LOTS operation will be inextricably enmeshed in the general unloading of the amphibious task force and post D day convoys. Accordingly, a broad examination of the lighterage operations associated with these deployments is necessary to determine the possible deviations of LOTS operations from the planning factor estimates. The factors affecting LOTS operations and the resulting probable extensions of such operations are, therefore, examined in the following section of this report.

(C) SECTION III

ANALYSIS OF FACTORS AFFECTING THE LOTS MISSION (U)

A. (C) MILITARY SITUATION FACTORS (U)

1. (C) THE MODERN MOBILE ARMY (MOMAR) (U)

The Modern Mobile Army (MOMAR) concept envisions complete mobility of all elements of the combat division, together with their basic combat supplies using organic vehicles. This concept is further expanded by providing similar mobility in the first echelon of logistic support as represented by the MOBILE SUPPORT GROUP FORWARD (MSGF). It provides further for some 25 percent of supplies being mobile loaded in the next echelon of logistic support, the COMBAT SUPPORT BRIGADE.

The concept of a completely mobile combat, or combat support unit, eliminates the consideration of personnel and combat supplies as entities separate from their associated vehicles in the ship-to-shore movement. All are loaded for lightering to shore as a package and arrive at the lighter discharge point ready to roll. While this apparent simplification of through-the-beach discharge of mobile loaded forces eliminates much of the congestion of material and handling equipment at the beach, the sheer numbers of vehicles involved will seriously tax beach capacities.

The ship-to-shore transport of mobile loaded vehicles by conventional water borne landing craft only serves to re-emphasize the stringent criteria of the past with regard to sea approaches to the beaches, surf conditions, beach gradient and beach obstacle clearance. It places added emphasis upon good trafficability through the beach and upon the traffic capacities of beach exits to assembly areas and inland movement routes. Interruption of traffic flow, with resulting traffic congestion,

must be avoided at all cost. It is essential, therefore, that the lighterage discharge points and route capacities therefrom equal, or exceed, the discharge capacities of the lighterage employed. The possibilities of alternate discharge sites and inland vehicular routes must be fully exploited as they are uncovered by the developing military situation. Lighterage, whose operational characteristics may serve to exploit every possible expansion of the through-the-beach operation, are highly desirable. Utilization of a portion of the assault lighterage in later resupply operations to fully exploit all the possibilities of the current concepts of resupply is likewise an end to be sought.

2.(U) SHIPPING (U)

The nature and amount of shipping available for an operation will have a marked influence upon the means employed in its unloading. Amphibious shipping, designed and equipped to transport and land the assault elements of the landing force, will have its use confined generally to that purpose. The forces required for the build-up of combat strength and a base of operations within an established beachhead must, of necessity, be transported to the objective area in MSTS and commercial type shipping. Combat loading (as defined in FM 101-10) is an objective to be sought if availability of shipping permits. Combat loading is fully compatible with through-the-beach discharge of the fully mobile combat forces visualized for the future. Where practicable, selective loading (as defined in FM 101-10) of resupply shipping will similarly permit full exploitation of the LOTS concept in distribution of supplies to dispersed transfer and unloading sites ashore and will facilitate intersite distribution of emergency and high priority supplies.

The characteristics of amphibious and merchant shipping taken on a fleet-wide basis are probably the slowest in the military arsenal to reflect significant changes. Equipment designed to accommodate advances in cargo handling techniques and equipment aboard ship must be economically useable with older methods, or suffer highly restricted useage. Accordingly, lighterage designed for use in the LOTS operation must be able to work conventional ships of today and, at the same time, take full advantage of improvements that may be introduced either through new construction or modification of older ships.

New construction may well include shipping especially designed and equipped for rapid and efficient handling of containerized cargo; roll-on and roll-off ships for handling vehicles and mobile loaded cargo; and clear hold shipping that facilitates the shipboard handling of all classes of cargo. It can be

anticipated that new construction will have increased capacity cargo handling gear with minimum safe working loads of 10 long tons. Older shipping may have its gear modified to provide similar capacities with either burtoning gear or shipboard cranes installed (Reference 48). Tests of the latter have shown increased unloading rates of as much as 22 percent (Reference 3) because of the latitude permitted in the fore and aft positioning of cargo for pick-up in the hold and in lowering it over the side. In summary, we may expect in the 1965 to 1970 time period to encounter in LOTS operations an increasing number of ships' hatches served by 10 ton booms with 20 foot outreach from the ship's side and with significant improvement in hatch rates associated with improved cargo handling aboard the ship. Hatch rates of 40 tons per hour for containerized cargo, 15 tons per hour for palletized cargo and 10 tons per hour for bulk and filler cargo have been operationally demonstrated and must be expected and handled by lighters working a ship. These changes in ships' cargo handling characteristics will increase significantly the number of holds in which heavy lift cargo can be loaded for LOTS discharge and the required number of lighters of sufficient capacity to work such holds. Lighters with increased productivity are, therefore, to be sought.

3.(U) <u>EXISTING LIGHTERAGE</u> (U)

Full consideration should be taken of lighterage in the inventory. Waterborne lighters include the LCM-6, the LCM-8, the LCU and the Beach Discharge Lighter (BDL). The family of amphibious lighters include the LARC-5, the LARC-15 and the BARC. Specific characteristics of the amphibious lighters will be detailed as their use is included in the comparative analysis of the lighterage operation. Collectively, they may be classified as low speed lighterage. Those in the waterborne classification must be discharged at the beach in the conventional manner of World War II with their use in the modern concept restricted primarily to the through-the-beach discharge of mobile loaded vehicles. As a family of varying load capacity lighters, they are capable of handling the entire range of service vehicles.

The amphibious lighters have been designed as a family to satisfy the requirements for over-the-shore transfer in the LOTS mission. The LARCs are primarily used in the discharge of bulk, palletized and containerized cargo, although the LARC-15 has some capability in the transport of vehicles. The BARC is fundamentally used for lighterage of vehicles. It has certain space limitations to be set forth later in regard to its ability to load to its weight capacity containerized and palletized cargo.

4.(U) HELICOPTERS (U)

While not a lighter in the true sense of the word, the helicopter has characteristics that make it competitive in the lighterage operation. Vertical envelopment by helicopter assault forces has gained general acceptance as a means of circumventing both natural and military obstacles. The helicopter has proven effective in both resupply and evacuation. Its use is an approved part of amphibious warfare doctrine with helicopter decks provided and projected within the amphibious forces to support helicopter assault forces. However effective the helicopter has proven in military operations, there appear to be practical limitations to its load capacity, and to the total lift that can be provided. This latter consideration becomes further constrained in the lighterage operation by the limited availability of helicopter decks and ships equipped with helicopter platforms. Within its capability to work individual classes of ships, the helicopter can be classified as a high speed triphibious lighter and will be included for comparative purposes in this analysis.

5.(C) OPERATIONAL CONCEPTS (U)

Military situation factors affecting lighterage operation are manifestly too numerous to list. Any actual operation will be based upon a military estimate and will reflect command decisions. The nature of the conflict whether general or limited, the political atmosphere with regard to the use of nuclear weapons, and the ready availability of such weapons to the potential or actual enemy will influence the final decision. While prudence dictates maximum passive defensive measures against a major military threat, expediency and economy of force may require recourse to less stringent measures and the acceptance of a calculated risk.

a. (C) Shipping Dispersal ~~(C)~~ (U)

Dispersal of the amphibious task force and resupply shipping has received major attention as a means of passive defense against nuclear and target seeking missile attack. The problem is further complicated by the submarine and mine threats that may prove equally devastating to individual ships. Dispersal patterns will be widely varied and all will tend to extend the over-water distances that lighterage must travel. The submarine will pose a definite threat to unloading ships and conceivably may dictate location of ship unloading sites at laterally extended distances from the seaward termination of the main supply route which they service.

Ship disposition and dispersion in a given operation will be based upon an analysis of the nuclear threat, submarine threat, conformation of the coast line, mine clearance, anchorages, weather, priority of unloading and countless other factors. The unloading of an individual ship will be expedited when all hatches are worked continuously at their maximum rate. Lighterage forces required to work the ship at maximum rates depend upon lighter speeds, hatch rates, distances traveled, and lighter unloading rates.

Figure III-1 graphically illustrates the effects of these variables upon total lighterage required to sustain a cargo rate equivalent to the attainable hatch rate. While force requirements for a given type of lighter are roughly proportional to cargo hatch rates, there is a wide variance in the rate of force increase between high and low speed lighters with equivalent increases in operating distances. It becomes evident that lighter operating speed soon becomes a determining factor in establishing the distance to which the LOTS operation can be extended economically.

While it is to be expected that ships will be moved in-shore as far as practicable to facilitate transfer, dispersal requirements in a major operation will require that many ships be unloaded at an extended distance from shore. Selective unloading of limited amounts of priority cargo from individual ships is highly probable in replacing battle losses and as a means of overcoming unforeseen contingencies. The ability to do so rapidly and economically, without the delay involved in shifting a ship to an inshore anchorage, is an inestimable advantage accruing from the use of high speed lighterage. An analysis of system costs for extended lighterage distances will determine the practicable limitations to which such operations can be extended and be pertinent in developing operational concepts for high speed lighterage equipment.

b.(C)<u>Lighterage Operations</u> (U)

The military lighterage operation in its simplest consideration is the cyclic operation of lighters associated with the discharge of cargo from a single ship. Even within this comparatively simple operation, sufficient variables in operating conditions are encountered as to require control and adjustment in the dispatch of individual lighters if an efficient operation is to be sustained. The multiplicity of variables that will be encountered in lighterage operations in support of an amphibious assault, or a theater resupply operation, only tend to emphasize the requirements of control and rapid response

(U) LIGHTER REQUIREMENTS

LIGHTERS REQUIRED PER SHIPS HATCH - VARYING WATER DISTANCE
LAND DISTANCE = 5 N.MI., LAND SPEED = 15 KN., PAYLOAD = 15 TON
CARGO FLOW RATE = SHIPS HATCH RATE (H.R.)

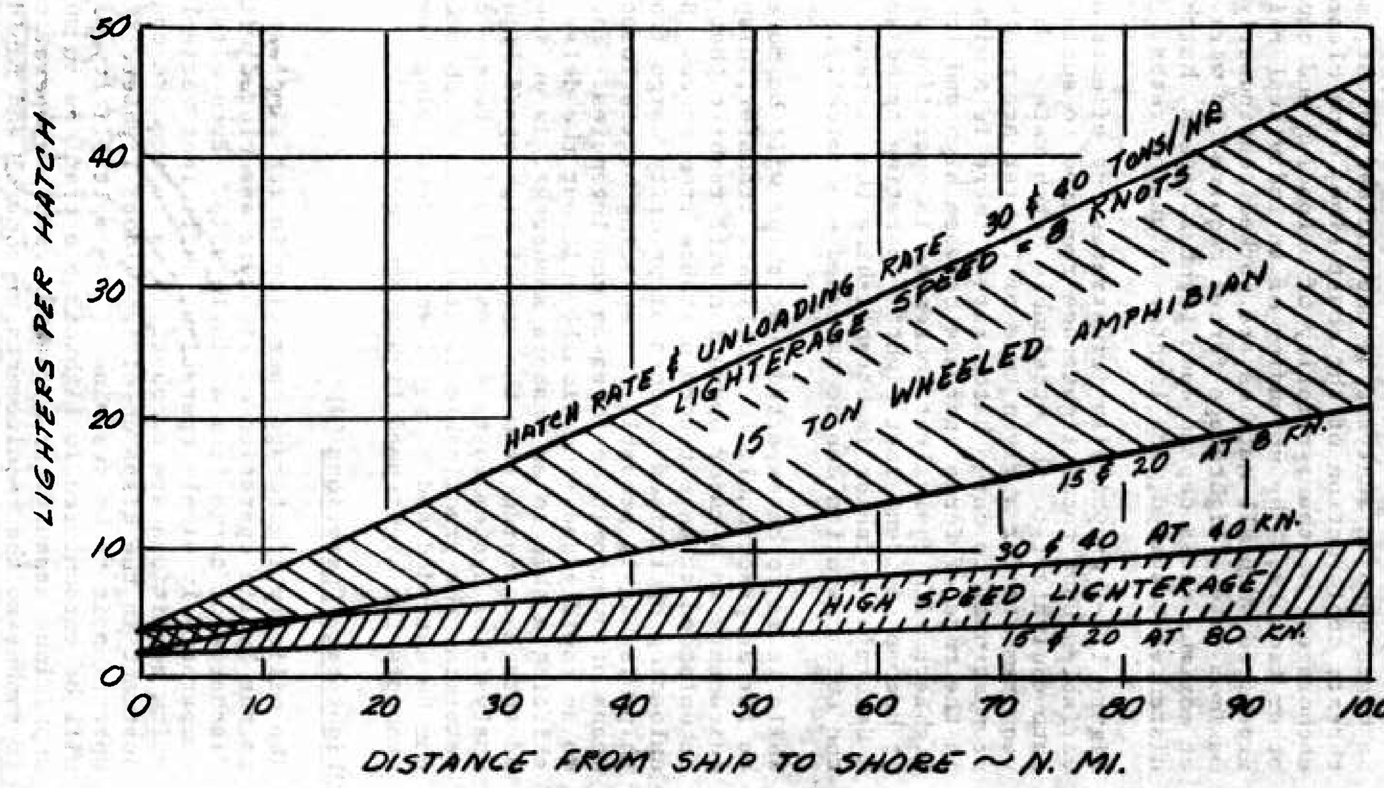


Figure III-1

to the military situation if lighterage is to be profitably employed. The wide dispersal of ships in both the amphibious assault and resupply operations is matched by similarly dispersed storage and transfer points ashore. The selective assignment of lighters to the priority unloading of individual ships and their subsequent direction to the appropriate discharge point ashore is essential in the ship-to-shore movement of combat forces and military cargo.

Fortunately, the introduction of advanced electronic stock control systems, with their prodigious capacity for data processing and transmission, have made possible the continuous tracing of cargo in transit and affords the theater logistic agencies a means through selective unloading to rectify errors in planned cargo distribution and to fill localized shortages produced by underestimated expenditure rates or in-transit casualties. The capability permits an interdependency between cargo discharge sites and may well produce a demand for intra-theater lighterage operations as well as for concentration of lighterage at single sites to achieve maximum unloading rates of high priority cargo with subsequent direct delivery to forward positions inland. One of the principal factors in response to such demands will be the speed of the lighter and its ability to load cargo directly from all types of shipping. Lighterage reaction times becomes increasingly important as the efficiency of the controls improves.

The required range of the air cushion lighterage vehicles is, as indicated previously, dependent upon operational concepts and doctrine. Current concepts indicate over-water radii of up to 20 miles (Reference 2) with limited inland travel (2 to 6 miles). As the threat of nuclear warheads and homing missile technology increases, it is anticipated that greater dispersion of shipping both laterally and in depth will result in over-water radii up to 75 nautical miles. Additionally, these factors and limited beach entrance and exit capacities may well require inland radii up to 10 nautical miles.

Greater operational use of CONUS addressed supplies shipped in containerized units, and automated inventory and supply distribution data handling techniques will permit the introduction of ship-to-user lighterage operations. Lighterage transport from ship-to-user would result in even greater inland mission radii. The military necessity and constraints coupled with the less important economic considerations should dictate the LOTS operation concepts and doctrines. In no case should future LOTS operation concepts and doctrines be predicated upon limitations imposed by existing lighterage equipment capabilities. The

radii of operation permitted by existing slow speed lighterage constrain the LOTS operation to close in to shore with a corresponding concentration of shipping even though tactical and strategic military considerations dictate a much wider dispersion.

c.(C) Response Time (U)

Response time is a result of the effectiveness of the lighterage control system, the transit distance involved and the lighter speed. Within a local lighterage operation, the diversion of lighterage to secure priority unloading of selected cargo or to avoid queuing in cyclic operations is essential. Given comparable effectiveness of the control system, the reaction time of the high speed lighterage is the more favorable with the advantage increasing with the distances involved.

A second facet of response time is in the capability to redeploy lighterage between unloading sites to achieve maximum site unloading rates and to obtain high productivity with minimum total means. Again the greatest capability lies in the high speed lighter with its elapsed response time governing the distance over which it becomes practical to make such deployments. Similarly, the the intersite discharge and distribution of priority cargo will depend, to a large extent, upon the time and distance over which high speed lighterage can be operated economically.

While far from eliminating all the factors involved, the availability of high speed lighterage will broaden the practical base of rapid cargo distribution and shorten the response time in making emergency issue of cargo as it arrives aboard ship in the theater of operations.

d.(C) Navigation, Command and Control (U)

A military system must perform under conditions imposed upon it by all the ingenuity of a resourceful enemy. An unfavorable environment may be self-imposed as a screen against enemy interference and a protection against unacceptable losses. A major factor in many successful military ventures has been the ability to operate effectively at night, or under low visibility conditions. In view of the above, it is considered that a capability of conducting lighter operations at night or under conditions of low visibility is essential in obtaining high lighterage productivity, rapid ship unloading and turn around, and as added insurance against prohibitive enemy interference.

During the hours of daylight, fog becomes an increasing hindrance to navigation as its density increases. It does not

normally become a major impediment to work requiring short range visibility, such as that involved in the transfer of cargo from ship to lighter. Darkness generally slows operations except as it is relived by artificial illumination. The combination of fog and darkness may compound effects by adding the reflected glare of artificial illumination to the obscurity produced by fog.

It has been demonstrated that ship unloading can be conducted with infra-red illumination and that infra-red guidance and signaling in clear weather are practical. Infra-red penetration of fog is insufficient to provide an accurate guidance system for lighterage navigation, therefore radio navigation techniques may have to be used. Traffic separation and obstacle avoidance are equal in importance with the accuracy of navigation in low visibility operations. Equipment and methods for mission accomplishment under such adverse conditions should be incorporated within the vehicle.

Overland navigation, if anything, must be even more precise than that employed over water as obstacle avoidance distances will generally be considerably less. Means of guidance and communication dependent upon line-of-sight propagation will be limited in application by the contour of the terrain traversed. It is desirable that means of navigation and control of amphibious lighterage have maximum applicability in both overwater and overland operations.

6.(C) <u>Conclusions</u> (U)

a. The LOTS mission may be initiated separately, as a part of the amphibious assault, or in connection with the lighterage operation pertaining to the build-up of theater forces. Economy of force dictates that lighterage designed to fulfill the LOTS mission have application and acceptable performance throughout the spectrum of lighterage missions.

b. Military lighterage must be able to work all classes of ships under all environmental conditions that permit the ship to work its holds and safely discharge cargo over the side.

c. Extension of the radius of operation of military lighterage with acceptable productive rates and good response time at acceptable cost will afford an increased flexibility in the LOTS operation. This flexibility is of inestimable value in attaining a desirable dispersion

of the ship unloading operation in the face of the nuclear, homing missile and submarine threats.

d. An effective means for the control and dispatching of lighterage is essential to any extensive lighterage operation.

e. The capability of rapidly concentrating lighterage under its own power from distant unloading sites affords a means of attaining maximum unloading rates of priority cargoes, as well as a means of quickly adjusting theater lighterage distribution to replace local losses or to meet changing military demands.

f. The introduction of modern stock control equipment and procedures will permit continuous tracing of military shipments and provide information needed for selective unloading and distribution of high priority cargo.

g. Inter-site discharge and distribution of selected cargo is a desirable operation and feasible within the limiting characteristics of the lighterage employed.

h. Developments of equipment and techniques that may become operational prior to 1970 will certainly have a recognizable influence upon military lighterage employment. An examination of such influences and possible extensions of the current parameter values of the LOTS mission are indicated. Exploration of these extended parameters should be accomplished in any evaluation of the ACV as an amphibious lighter.

B. (C) CARGO CHARACTERISTICS (U)

1. (C) CARGO REQUIREMENTS (U)

The Army Division Slice furnishes broad logistic planning factors used in approximating the gross supply requirements in a military operation. The use of these factors within the present analysis is equally general in nature. They are used primarily to show variations in the character of cargo that may be handled at different periods in the theater lighterage operation and the wide variations that may occur in the magnitude of the operation as compared to that in the stylized LOTS lighterage mission.

The Division Slice has been used to establish the daily dry cargo resupply tonnage as a factor in the standardized LOTS mission with the distribution between general bulk and vehicular cargo established at 1080 and 360 short tons, respectively. While the Division Slice sets this average daily resupply requirement for the LOTS mission, it also represents an average grouping of combat and combat support elements that must be either predeployed or brought into the theater for general unloading. The Division itself represents cargo on the order of 25,000 short tons (Appendix III of Reference 4) of which from 80 percent to 100 percent may be mobile loaded vehicles. The complete division slice represents cargo on the order of 60,000 short tons (Reference 2) with a wide variance in the percentage of vehicular cargo associated with individual organizations. A general conclusion may be reached that the unloading of major combatant and combat support organizations with a very high proportion of vehicular cargo will represent a lighterage operation of major magnitude as compared to the standard LOTS lighterage mission and one in which all theater lighterage may be required.

2.(C) <u>CLASSIFICATION OF MILITARY CARGO</u> (U)

Analysis of cargo characteristics within general classifications is based as need be upon the organizational structure and equipment of specific combat and combat support units. However, the five classifications, Class I through Class V, of combat supplies as given in FM 101-10 (Reference 1) are inadequate for use in cargo analysis of the military lighterage operation. A classification into bulk fuel and dry cargo, with a further refinement within the latter classification, is basic to the lighterage problem. Although personnel is obviously not cargo in normal parlance, personnel transport is a form of lighterage operation that must be taken into account. Accordingly, personnel will be considered a third general category of lighterage cargo in the present study.

a.(C) <u>Bulk Fuel</u> (U)

Bulk fuel assumes importance as military cargo primarily because of its proportionate tonnage, its handling characteristics and the special means developed for its transport. Of the 1145 short tons daily fuel requirements of a Division Slice, as given in FM 101-10 (Reference 1), 882 short tons are bulk fuel. This tonnage is handled normally by tanker, through tanker discharge facilities, by pipeline to tank farms. Amphibious

lighterage should be considered as a secondary means of transport in case the fixed tanker discharge facilities are denied by enemy action. Installation of kit type tankage to provide capacity loads in the ACV lighterage is feasible, provided adequate provision is made for weight and balance adjustment and the tankage is compartmented and filled sufficiently to prevent free surface shift of the load to the extent that it endangers vehicle stability or control. With fuel and kit type tankage representing a comparatively high density cargo of approximately 50 pounds per cubic foot, cargo space dimensions are normally adequate for the utilization of the ACV as an amphibious tanker. The ACV will be implicitly evaluated in this utilization in the course of analyzing productivity. However, no consideration will be given to this application as a primary mission.

b.(C) Dry Cargo (U)

Military dry cargo can be classified as containerized, palletized, bulk and filler and vehicular. Containerized cargo is made up of lesser items packed in standard Conex containers of from 3 to 5 tons gross weight. Palletized cargo is packed on standard pallets with average gross weight of 1 ton and maximum gross weight of 1½ tons. Bulk cargo is of indeterminate size and weight, but individual items fall well within dimensional and weight limitations of the palletized and containerized classifications. Heavy lift cargo is assumed to be wheeled or tracked to provide ready mobility ashore. Accordingly, for the purpose of this analysis, all cargo exceeding the maximum 10,500 pound gross weight of the fully loaded, large size Conex container is assumed to be vehicular. In line with this assumption, and in light of war experience as modified by modern cargo handling techniques, it has been estimated in ORO-T-361 (Reference 5) that the spread of theater dry cargo, in the event of war, would be 16 percent palletized, 34 percent containerized, 25 percent vehicular, and 25 percent bulk and filler. Average hatch rates are likewise established in ORO-T-361 as 15 tons per hour for heavy lift cargo. A composite hatch rate of 16.4 tons per hour is derived from the assumed cargo spread and hatch rates for individual classifications. These general cargo characteristics are tabulated in the following table.

(C) TABLE III-I (U)

CARGO CHARACTERISTICS (U)

Type of Cargo	Percent	Limiting Dimensions L	W	H	Limiting Weight lbs.	Hatch Rate Tons/hour
Palletized	16	43"	52"	54"	3,000	15
Containerized	34	51"	75"	82½"	9,900	40
		102"	75"	82½"	10,500	
Bulk & Filler	25					10
Wheeled	25					15

The above generalizations can well be modified within the 1965-1970 time frame by changes in armed forces equipment, but probably not to the extent of the variation that will be encountered in normal operations.

Computations from Appendix III of FM 57-210 (Reference 4) indicate the bulk tonnage of an infantry division with 100 percent personnel and equipment, 3 days of rations and POL for 300 miles range, to be approximately 23,728 short tons. Of this, 1,670 short tons, or 7 percent, are personnel; 3,368 short tons, or 14 percent, are equipment; and 18,690 short tons, or 79 percent, are made up of vehicles, guns and trailers. The MOMAR concept increases the proportion of vehicles even further by providing 100 percent mobile loading for the entire combat division and certain combat resupply elements.

In view of the high proportion of vehicles that may be expected to be included in military cargo, it is considered appropriate that the lighterage of such vehicles be given detailed scrutiny. Accordingly, the general unloading of vehicles of selected major combat and combat support elements are chosen for detailed consideration. Lighterage that will accomplish this task will serve adequately to unload the less critical spread of general cargo anticipated in shipments of resupply materials.

An analysis of major organizational equipment in the ROTAD, ROCID, ROCAD, ROTAD SUPPORT UNITS, ROCID SUPPORT UNITS, and the 762 mm Rocket Battalion, as tabulated in the Transportation System Study PRC R-88 (Reference 6), establishes a distribution of vehicles by numbers and weights as shown on figures III-2 through III-7.

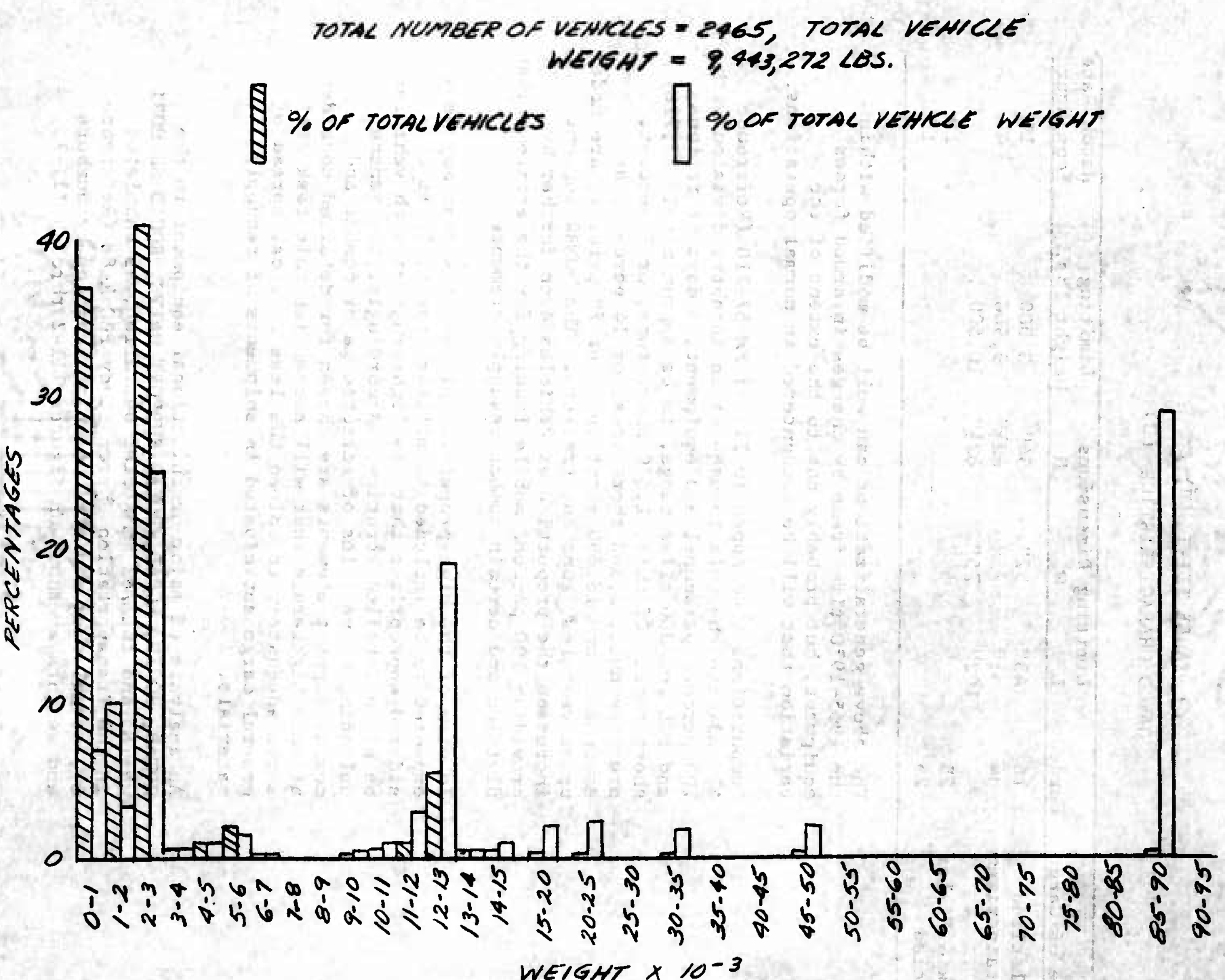


Figure III-2. (C) Division (ROTAD) Vehicle Distribution by Numbers and Weight. (U)

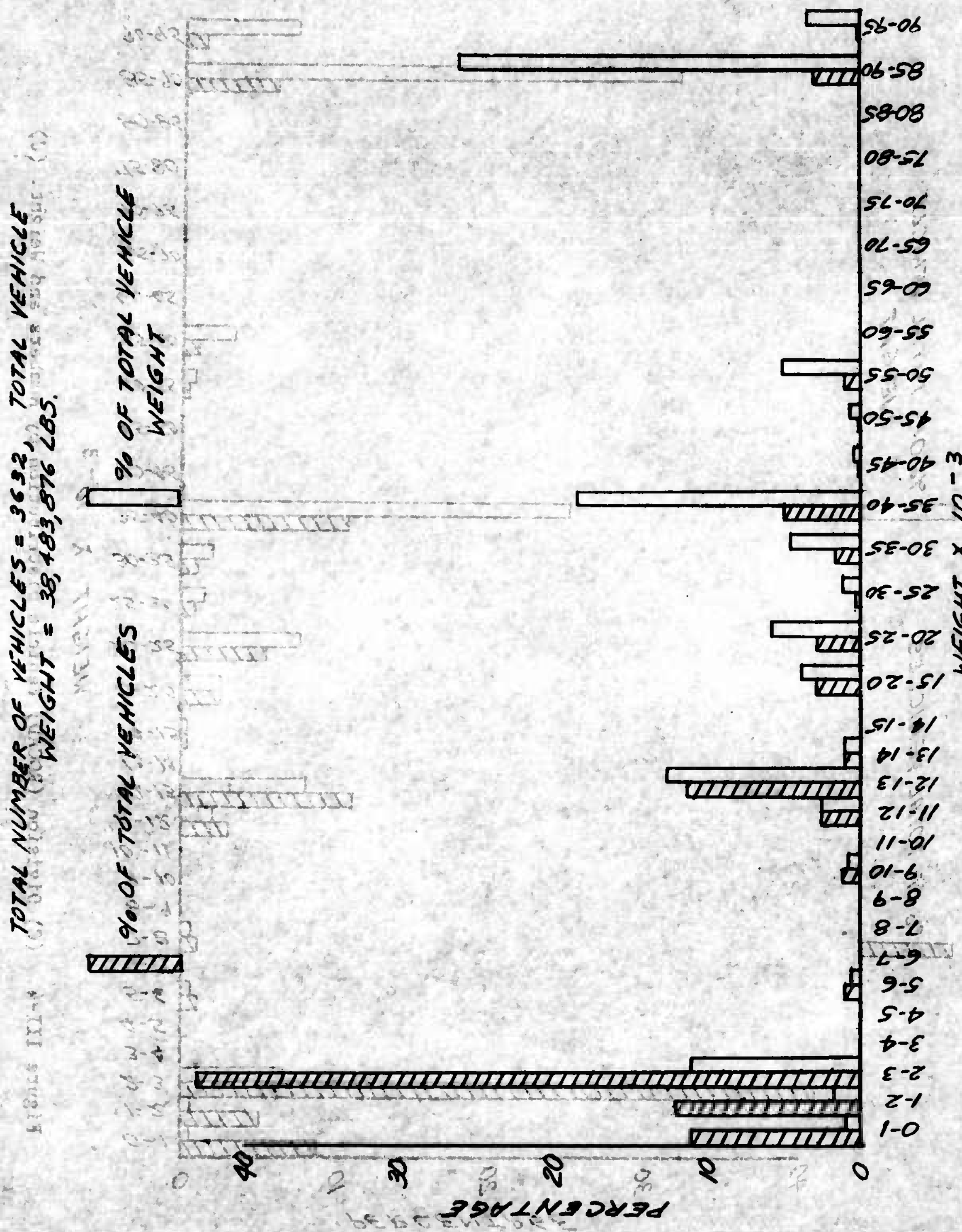


Figure III-3. (C) Division (ROCID) Vehicle Distribution by Numbers and Weight. (U)

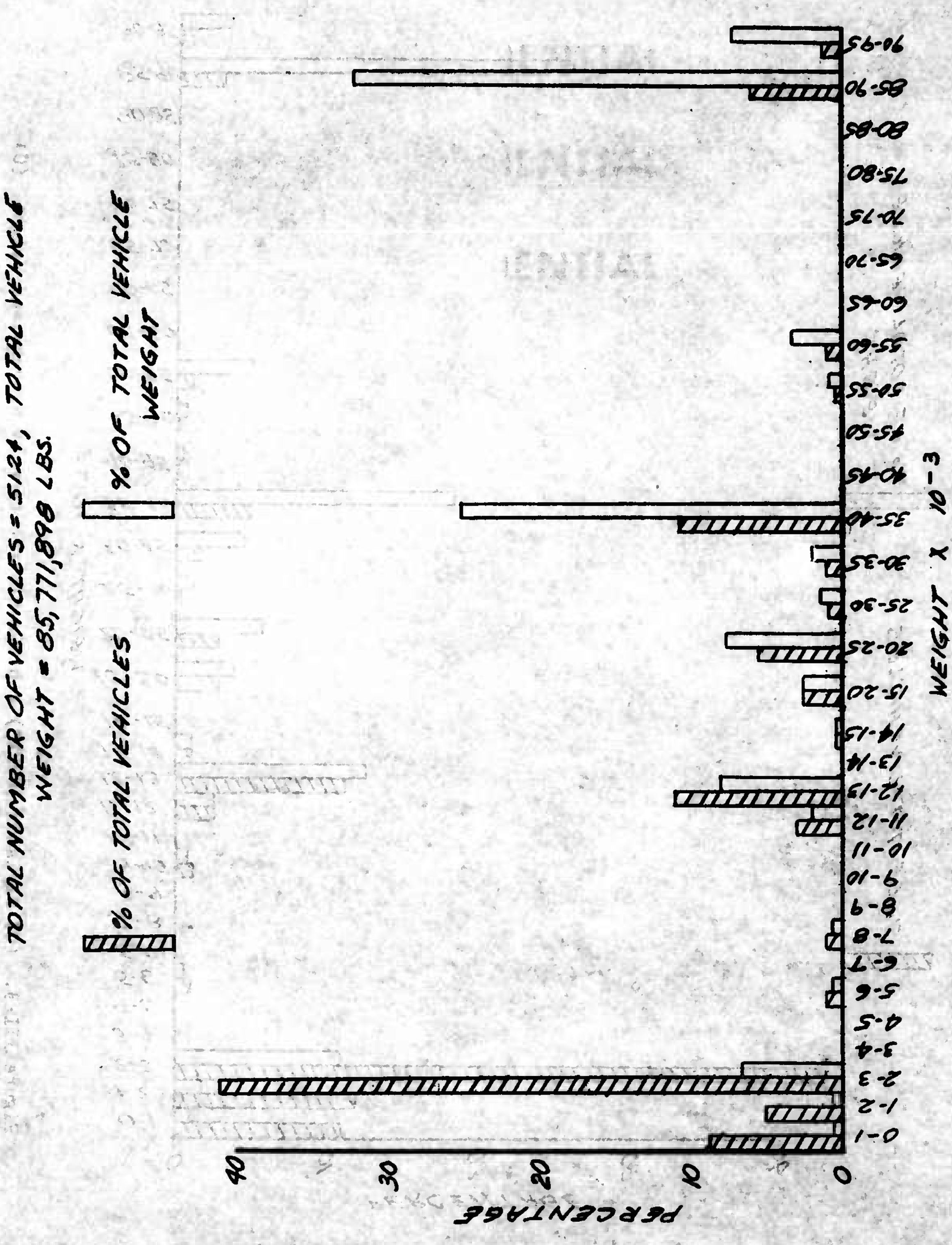


Figure III-4. (C) Division (ROCAD) Vehicle Distribution by Numbers and Weight. (U)

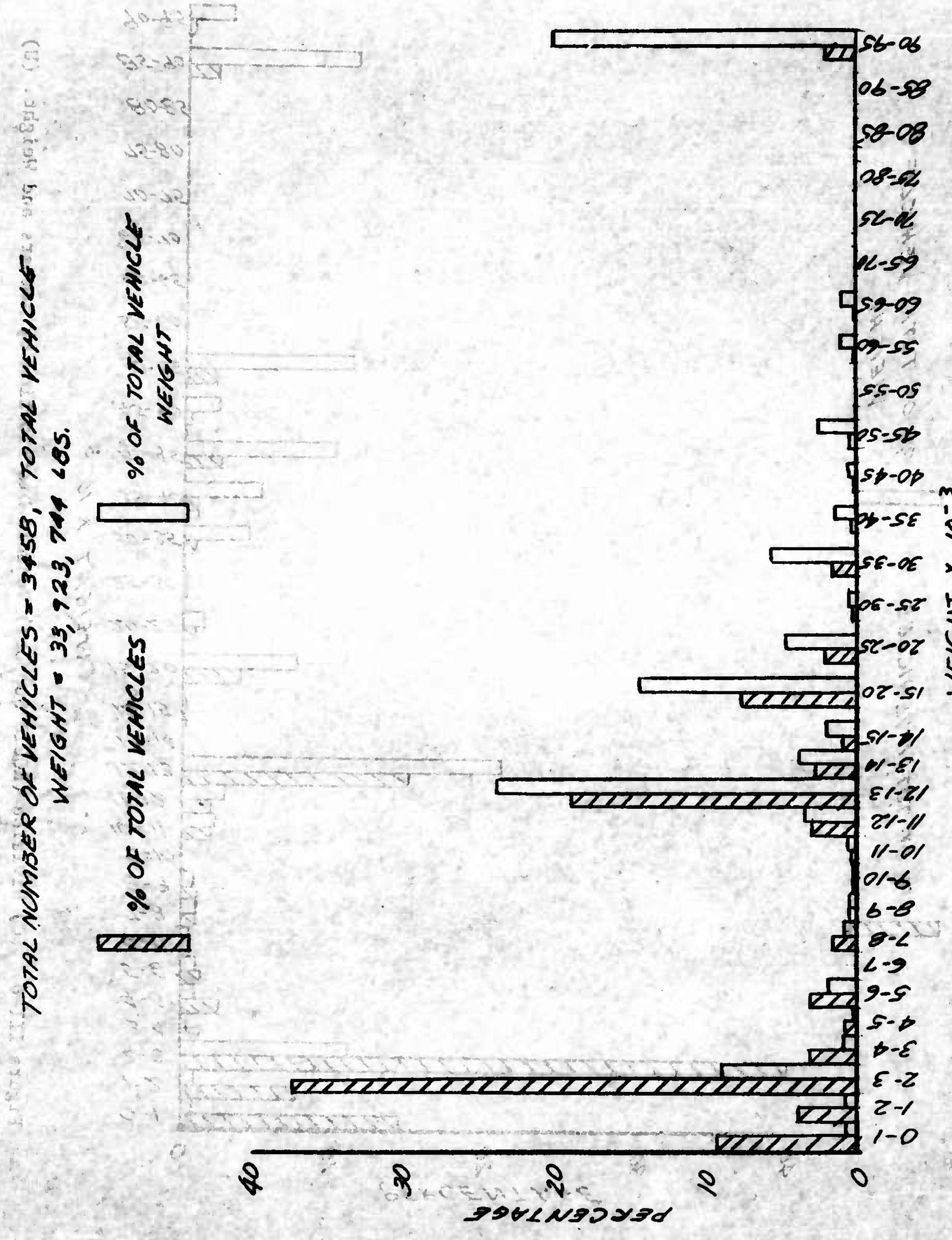


Figure III-5. (C) Division (ROTAD Support) Vehicle Distribution by Numbers and Weight. (U)

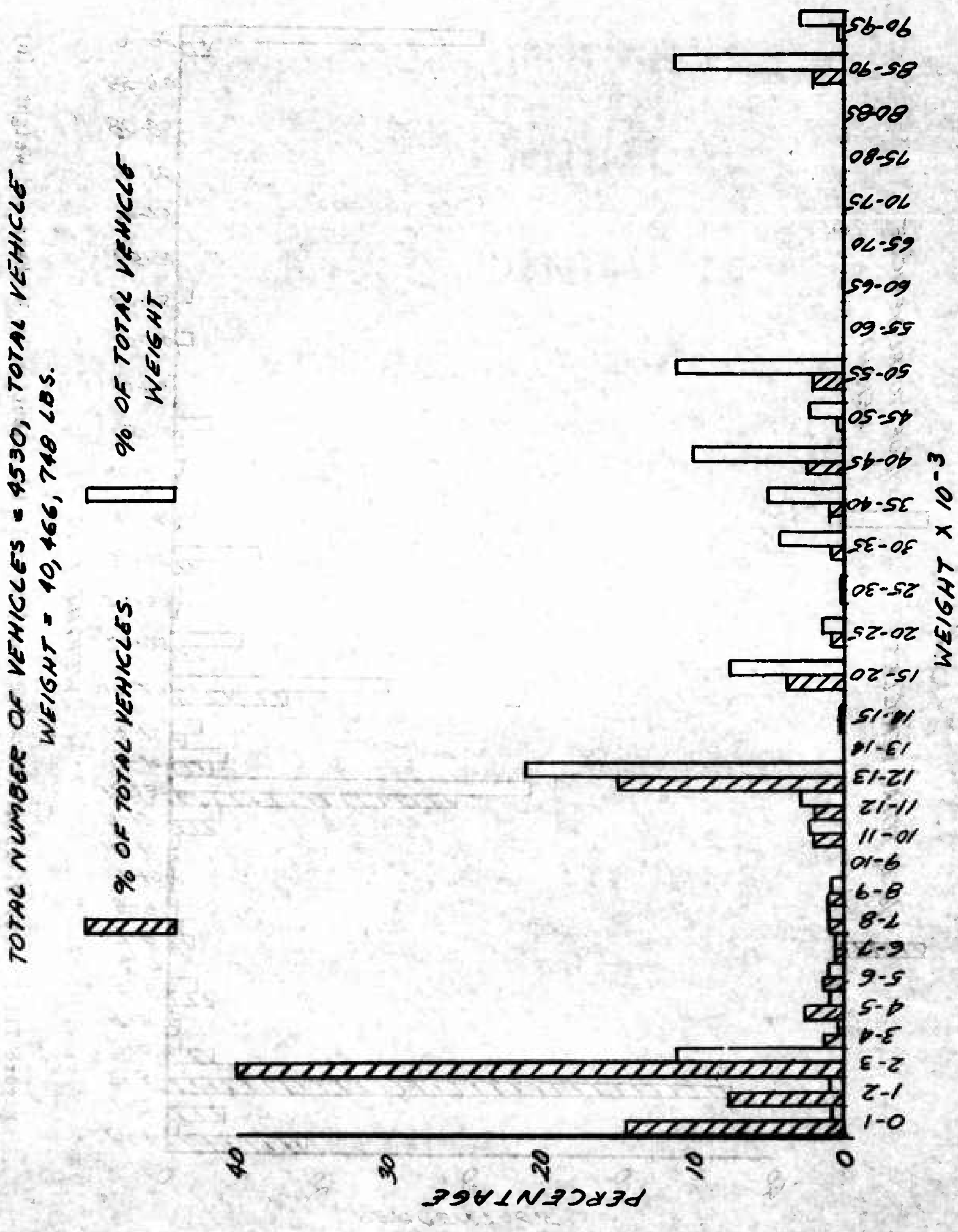


Figure III-6. (C) Division (ROCID Support) Vehicle Distribution by Numbers and Weight. (U)

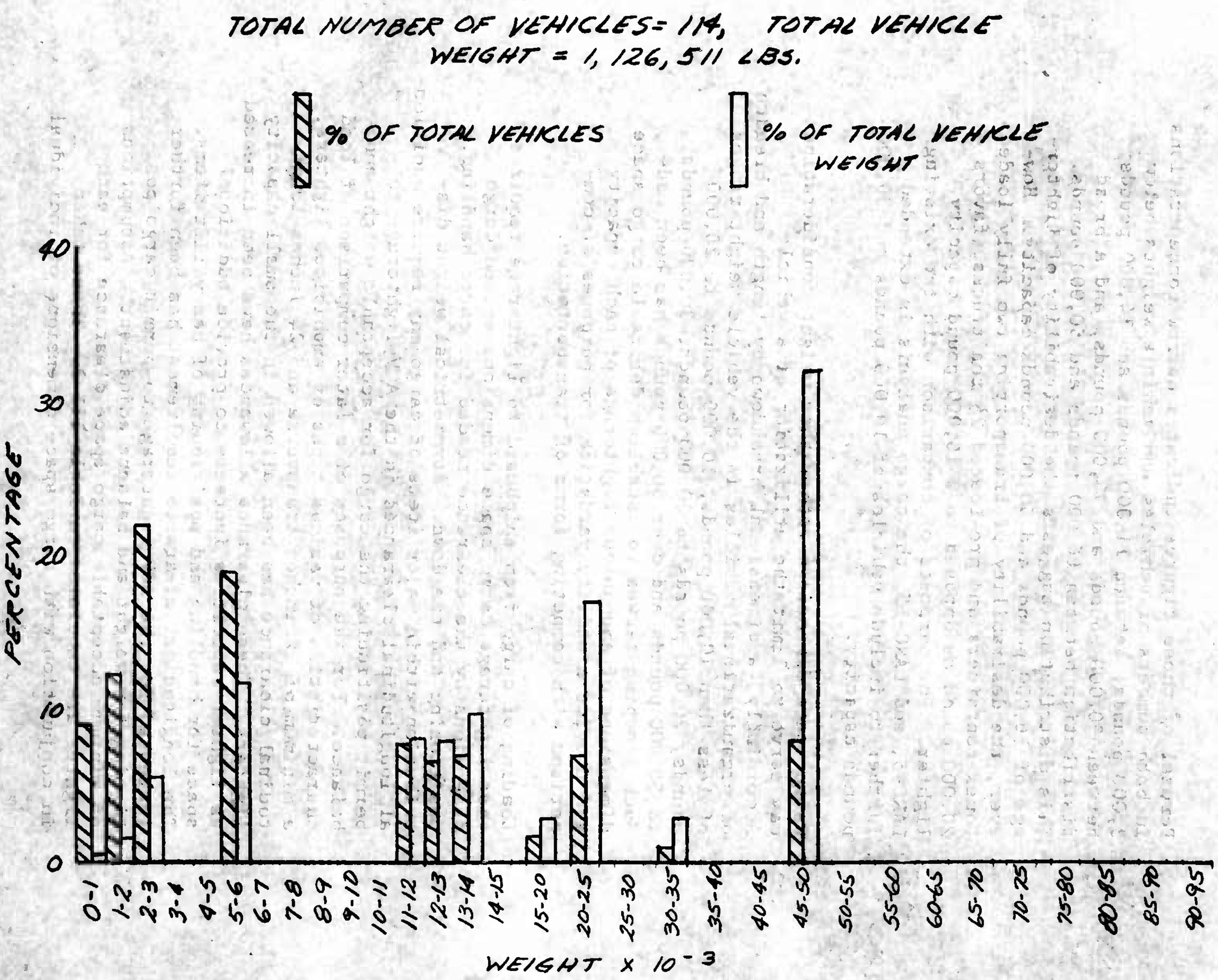


Figure III-7. (C) Battalion (76 MM Rocket) Vehicle Distribution by Numbers and Weight. (U)

Perusal of these figures indicates narrow concentrations in both numbers of vehicles and vehicle weights below 3,000 pounds; between 11,000 pounds and 14,000 pounds; between 90,000 pounds and 94,000 pounds; and a broad distribution between 16,000 pounds and 50,000 pounds. This distribution suggests the desirability of lighterage of 16,000 pounds and 50,000 pounds capacity. However, the desirability of transporting two fully loaded Conex containers and pre-loaded 2½ ton trucks, favors a 20,000 pound as opposed to a 16,000 pound capacity lighter. For purposes of comparison with the existing LARC-5, and LARC-15, the cargo analysis is extended further to include vehicles of 10,000 pounds and 30,000 pounds capacity.

Cargo space dimensions rather than weight considerations may serve to limit the utilization of a vehicle. Accordingly, a dimensional breakdown by length and breadth of organizational vehicles in the vehicle weight ranges of less than 10,000 pounds, 10,000 pounds to 20,000 pounds, 20,000 pounds to 30,000 pounds, 30,000 pounds to 50,000 pounds and over 50,000 pounds has been made. Such grouping serves to establish desirable cargo space dimensions of amphibious lighterage of each capacity and provide a utility yardstick for purposes of comparison with competing forms of transportation.

Loading of cargo from shipboard to lighterage requires that lighterage cargo space dimensions exceed cargo dimensions by the clearance needed for cargo handling, positioning and tie down. Asymmetrical weight distribution within major items of cargo may require additional longitudinal clearances in the ACV lighterage to permit positioning the cargo for acceptable weight and balance. For the purposes of a later comparison of load characteristics of various types of amphibious lighters, a minimum of 12 inches transverse and 24 inches longitudinal clearance has been allowed in the small capacity lighters. These clearance allowances have been increased as lighter capacities increase to provide additional space for handling and positioning of heavy lift items. The longitudinal clearance requirement has been further increased for the ACV lighterage to permit cargo positioning for weight and balance adjustment. Assumptions of minimum acceptable cargo space clearance for each lighter are tabulated in Table III-2. These taken in conjunction with cargo space dimensions of individual

(C) TABLE III-2 (U)

LIGHTER CARGO SPACE DIMENSIONS (U)

TYPE OF LIGHTER	CARGO SPACE Plan Dimensions	LOADING CLEARANCE Transv.	LOADING CLEARANCE Long.	LIMITING CARGO DIMENSIONS	SPACE LIMITED Conex Container (102"x75"x82½") LOAD	SPACE LIMITED SINGLE Tier Pallet (43"x52"x54") LOAD
LARC-5	91½" x 191"	12"	24"	79" x 167"	1	4
ACV 5 Ton	108" x 300"	12"	36"	96" x 264"	2	10
ACV 10 Ton	108" x 360"	12"	36"	96" x 324"	4	12
LARC 15	120" x 288"	18"	30"	102" x 258"	3	8
ACV 15 Ton	132" x 420"	18"	42"	114" x 378"	5	16
ACV 25 Ton	156" x 468"	24"	48"	132" x 420"	5	24
BARC (60 Ton)	168" x 462"*	24"	36"	144" x 426"	8*	26*

* Data from Reference 7 (AD-11453)

amphibious lighters, develop the limiting plan dimensions of items of cargo that may be loaded readily in the cargo space of each type lighter. Indicated also, in this same tabulation, are the limiting numbers of the larger size (102" x 75" x 82½") Conex containers and of standard pallets that can be loaded single-tiered into each cargo space.

The organizational vehicle compilations in Reference 6 for the ROTAD, ROCID, ROCAD, ROTAD Support, ROCID Support and the 762 mm Rocket Battalion were further arranged by weight and plan form dimensional groupings. The percentages, by number and weight of vehicles that could be loaded within the cargo weight and cargo space limitations of the LARC-5, and LARC-15, the BARC and hypothetical ACVs with selected weight capacity and cargo space dimensions were determined. Because of the singular characteristic of the ACV that permits trade-off of operating height for greater payload capacity under favorable operational environments, a further investigation was made of the additional capability to carry organizational vehicles accruing to the hypothetical 10 ton capacity ACV operating within a 50 percent overload limitation. Hypothetical lighters of similar weight capacity, but unlimited cargo space, are listed as a basis of comparison. The results of these investigations are delineated in Table III-3.

Each of the listed amphibious lighters suffers in its ability to transport organizational vehicles when compared to a hypothetical lighter of equal capacity but unlimited cargo space. As is to be expected, the degradation of capability increases markedly with the increased restriction imposed by cargo space limitations. As shown graphically in Figures III-8 and III-9, the large cargo space of the 5 ton capacity ACV lighter permits it to load substantially the same percentage of organizational vehicles as does the LARC-15. The 10 ton capacity ACV is markedly superior to the LARC-15 in this respect, while the selected 15 ton capacity ACV lighter falls only slightly short of a hypothetical lighter of unlimited cargo space in its capacity to load organizational vehicles weighing 15 tons or less.

TABLE III-3

(C) ORGANIZATIONAL VEHICLES
TRANSPORTABILITY BY AMPHIBIOUS LIGHTERAGE (U)

TYPE	CARGO SPACE PLAN DIMENSIONS	LOAD CLEARANCE Trans-verse	LOAD CLEARANCE Longi-tudinal	LIMITING CARGO DIMENSIONS	ROTAD % Veh.	ROTAD % Wt.	ROCID % Veh.	ROCID % Wt.	ROCAD % Veh.	ROCAD % Wt.	ROTAD SUPPORT % Veh.	ROTAD SUPPORT % Wt.	ROCID SUPPORT % Veh.	ROCID SUPPORT % Wt.	762 m.m. Rkt. Bn. % Veh.	762 m.m. Rkt. Bn. % Wt.
LARC-5	91½"x 191"	12"	24"	79" x 167"	81.4	32.2	54.1	9.9	36.2	4.4	35.5	7.2	43.9	8.8	41.2	7.5
5 Ton ACV	108 "x 300"	12"	36"	96" x 264"	88.5	37.5	67.8	13.8	55.6	7.6	57.4	14.3	66.3	16.1	62.3	19.5
% Ton Lighter	Unlimited			Unlimited	90.0	38.9	69.1	14.2	57.1	7.9	59.3	15.3	68.3	17.4	62.3	19.5
10 Ton ACV	108 "x 360"	12"	36"	96" x 324"	95.5	59.5	82.5	31.3	70.0	18.5	80.7	43.4	88.3	46.5	75.5	37.0
10 Ton ACV (50% Overload)	108 "x 360"	12"	36"	96" x 324"	95.5	59.7	82.8	31.9	70.0	18.6	81.5	45.0	88.4	46.6	75.5	37.0
10 Ton Lighter	Unlimited			Unlimited	98.1	65.3	86.0	34.9	73.4	20.5	92.9	63.5	91.1	51.2	84.2	47.9
LARC-15	120 "x 288"	18"	30"	102"x 258"	89.3	40.4	69.0	15.1	57.7	9.4	58.9	15.9	67.0	17.0	69.5	28.9
15 Ton ACV	132 "x 420"	18"	42"	114"x 378"	96.0	62.1	86.2	38.4	76.5	27.0	93.0	64.5	88.5	52.0	83.5	46.7
15 Ton Lighter	Unlimited			Unlimited	98.4	67.6	88.9	41.8	79.5	29.4	95.0	68.4	91.7	52.6	91.2	65.0
25 Ton ACV	156 "x 468"	24"	48"		96.7	66.0	94.5	63.9	90.5	56.4	95.5	71.6	95.4	73.3	96.7	83.2
25 Ton Lighter	Unlimited			Unlimited	98.8	71.4	95.5	65.2	91.6	57.1	97.3	76.5	96.7	75.0	100.0	100.0
BARC (60 Ton)	168 "x 462"	24"	36"	144"x 426"	99.0	95.5	99.6	98.6	99.5	97.5	98.7	96.8	99.7	97.2	96.7	83.2
60 Ton Lighter	Unlimited			Unlimited	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

Type	Vehicle Symbol	Cargo Space	Load Clearance	Limiting Cargo Dimensions
5 Ton ACV		108" x 300"	12" x 36"	96" x 264"
10 Ton ACV		108" x 360"	12" x 36"	96" x 324"
15 Ton ACV		132" x 420"	18" x 42"	114" x 378"
LARC-15		120" x 288"	18" x 30"	102" x 258"
15 Ton Lighter		UNLIMITED		UNLIMITED

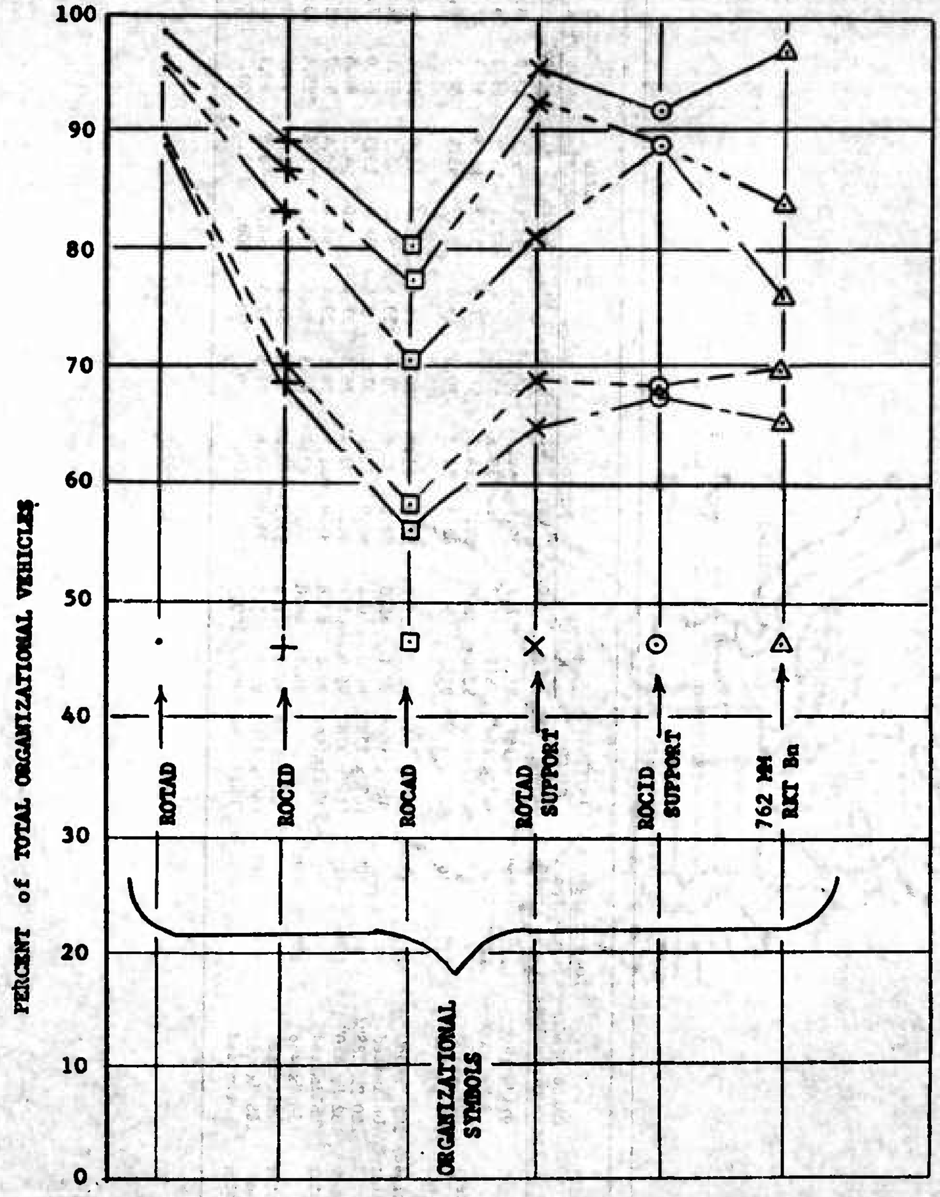


Figure III-8. (C) Organizational Vehicles. Transportability by Amphibious Lighterage. (U)

Type	Vehicle Symbol	Cargo Space	Load Clearance	Limiting Cargo Dimensions
5 Ton ACV	——— — ———	108" x 300"	12" x 36"	96" x 264"
10 Ton ACV	——— — — ———	108" x 360"	12" x 36"	96" x 324"
15 Ton ACV	—— – — – ——	132 x 420	18" x 42"	114" x 378"
LARC-15	— — — — — — —	120" x 288"	18" x 30"	102" x 258"
15 Ton Lighter	————————	UNLIMITED		UNLIMITED

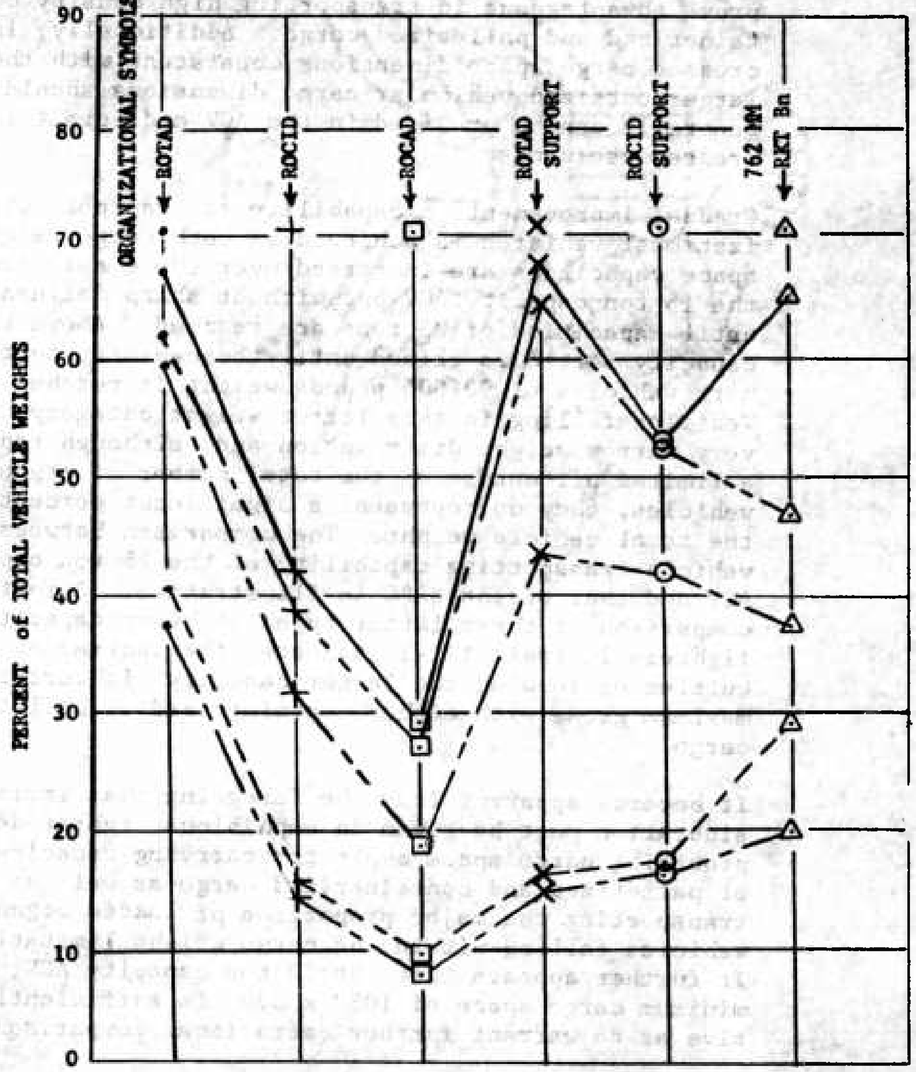


Figure III-9. (C) Organizational Vehicles. Transportability by Amphibious Lighterage. (U)

Returning again to Table III-3, it can be seen that the operation of the hypothetical 10 ton ACV lighter, with an allowed 50 percent increase in payload, shows little gain in its capacity to carry organizational vehicles. This stems from the limited number of vehicles in the 20,000 to 30,000 pound class, as well as the smaller cargo space dimensions chosen for this lighter, as compared to those chosen for the hypothetical 15 ton capacity ACV lighter. However, greater than design payload capacity in the ACV, as in all lighterage, can prove advantageous in transporting high density containerized and palletized cargo. Additionally, increased cargo space dimensions consistent with the larger outsized vehicular cargo dimensions should and generally can be provided in the ACV and permit increased usefulness.

Gradual improvement in capability to transport organizational vehicles is achieved as both cargo weight and space capacities are increased over those selected for the 15 ton capacity ACV but without sharp delineation until capacities of 25 tons are reached. Above this capacity little is gained until the capacity to transport vehicles of 90,000 pounds weight is reached. Vehicles falling in this latter weight category have a very narrow weight distribution and, although representing a limited percentage of the total number of organizational vehicles, they do represent a significant percentage of the total vehicle weight. The comparison between the vehicle transporting capability of the 25 ton capacity ACV and that of the BARC is illustrative. A further comparison of these latter types of heavy capacity lighters in Table III-2 indicates the increasing difficulties of loading the larger capacity lighters to their maximum gross with either containerized or palletized cargo.

It becomes apparent from the foregoing that serious consideration must be given in amphibious lighter design to providing cargo space ample for carrying capacity loads of palletized and containerized cargo as well as to transporting the major proportion of loaded organizational vehicles falling within the cargo weight limitations. It further appears that the 10 ton capacity ACV, with a minimum cargo space of 108" x 360" is sufficiently attractive as to warrant further operational comparison with

amphibious lighterage in the 5 to 25 ton capacity range. A further absolute requirement exists for lighterage of approximately 50 ton capacity with cargo space compatible with the dimensions of the largest military vehicle.

c.(U) Personnel

Personnel, as a separate item of lighterage cargo, will make up a very small proportion of the total lighterage tonnage but must, nevertheless, be considered. Personnel and supplies that are mobile loaded with their organizational vehicle become an entity with the vehicle once they are aboard the lighter. Mobile loaded supplies will generally be loaded in the vehicle prior to its loading aboard ship and will be handled as a unit with the vehicle from that time forward. Personnel will be loaded aboard the lighter separately from their associated vehicle but should be discharged from the lighter as a part of the vehicle load. The weight of both mobile loaded personnel and combat supplies must be considered in computing lighterage loads.

Restraint of personnel loaded in a lighter is essential as a safeguard against injury and shifting under accelerations that may be associated with operating conditions, or as a result of accident. The hazard to stability and control in an ACV due to a major shift in the center of gravity, requires some means of restraint of passengers in all operations. The possibility of utilizing those means of restraint provided within a mobile loaded organizational vehicle should not be overlooked.

3.(C) CONCLUSIONS (U)

a. Existing wheeled amphibians in the low and intermediate payload capacities are seriously limited by cargo space restrictions in their ability to accommodate the significant and growing proportion of vehicles and mobile loaded vehicles within their rated payload capacities. Similarly, the intermediate and heavy payload wheeled amphibians are restricted in ability to carry rated loads of single tiered palletized and/or Conex container cargoes. The economy and usefulness of the wheeled amphibians are, therefore, seriously degraded in their application to LOTS operations.

The cargo compartment size provided the ACV lighterage should be made adequate for transport of all vehicular equipments or single tiered general cargoes within its payload capacity to avoid reductions in effectiveness and operational economy.

b. The distribution of cargoes within the military inventory makes attractive the provision of lighterage with a minimum payload capacity of ten short tons. This minimum payload capacity provides for the transport of the major proportion of vehicular items or two Conex containers.

Provision for transport of equipments weighing up to approximately 50 tons is required for a small percentage of military equipment items which represent a significant proportion of the cargo weights. However, due to the heavier equipment's ground mobility it is not certain that they require ship to shore transport by amphibious lighters.

It is concluded, therefore, that the payload capacity in excess of ten tons resulting in maximum LOTS operation economy is the fundamental criterion for selection of the ACV payload capacity.

c. The general unloading of combat and combat support organizations in the theater of operations represents a lighterage operation of major magnitude, as compared with the discharge of resupply cargo represented in the LOTS mission. It further represents a much higher proportion of vehicular cargo within the overall distribution of cargo.

Minimization of lighter inventory and the necessity to effectively employ all available lighterage during amphibious operations dictate that the ACV lighter designed to satisfy the basic economic and operational objectives of LOTS operations provide acceptable performance during possible employment in the general unloading of combat and combat support organizations. Therefore, within its payload capacity, the ACV lighter should provide adequate space to transport the loaded vehicles of the combat and combat support organizations.

C. (U) CARGO HANDLING CONSIDERATIONS

Operational and technical characteristics of the ACV in the amphibious lighter application alter to some extent the requirements for cargo handling as compared to those used with waterborne lighterage.

Various means of modifying equipment and operational techniques suggest themselves to alleviate the problems associated with shipside maneuvering and cargo transfer. The most obvious methods seldom prove to be the most practical. The obvious way to eliminate relative movement between lighter and ship is to bring the lighter to static rest in or upon the ship. The use of specially-designed ships such as the Amphibious Assault Ships (LPH), Dock Amphibious Transports (LPD) and Dock Landing Ships (LSD) offer this feature, but such ships are so limited in numbers as to relegate their use to the special mission category. Few, if any, cargo ships have the deck space to accommodate lighters for loading direct from the holds. Even if they had suitable deck space and booms of sufficient capacity were available, the task of hoisting the lighter aboard and subsequently launching it would be a difficult and time consuming operation. Ramps upon which the lighter can climb aboard are apt to be cumbersome to rig and impracticable to tend in a seaway. The use of a barge or other type platform along side a ship to serve as a lighter landing and cargo transfer point not only imposes an additional cargo transfer upon an already complex operation but even further complicates the monumental task of transporting equipment to the theater of operations. All ancillary equipments that must be employed require stowage and maintenance when not in use as well as means of rapid movement between working locations.

Typical problem areas associated with cargo handling in lighterage operations, together with possible operational or technical solutions in the ACV lighter application, are discussed in the following paragraphs.

1. (U) CARGO POSITIONING

The ACV lighter will have a requirement for weight and balance control since the allowable center of gravity travel is expected to be on the order of three percent of the corresponding directional air cushion dimension. Vehicular cargo can be rolled into position after being brought aboard the lighter. However, the large non-mobile cargo drafts present the alternative of either lowering them into exact position or providing means within the lighter for positioning them after they are

deposited aboard. The first alternate offers a singular difficulty when it is realized that the burtoning gear with which most ships are rigged provides for lateral positioning, but no means for adjusting the fore and aft position in which it deposits the cargo draft. Therefore, any substantial adjustment in the fore and aft position in which a cargo draft is deposited in the lighter must be accomplished by warping the lighter into proper position under the ship's boom. This maneuver is to be avoided since it can be time consuming and thus can prolong inordinately the cargo hook cycle time. The second alternate is a means within the lighter for fore and aft positioning of non-mobile cargo; for weight and balance adjustment in loading and to permit taking aboard cargo from burtoning gear without warping the lighter to appropriate position beneath the cargo draft.

Considerations of cargo unloading at the inshore transfer point provide additional incentive for provision of cargo handling and positioning equipment within the lighter. Use of mobile cranes in the unloading of heavy (10,000 pound) non-mobile cargo on rough or soft terrain can be extremely difficult and hazardous. On the other hand, the exceedingly high weight of the 10,000 pound capacity rough terrain fork lift (27,400 pounds empty) provides concern that its loaded condition axle loads (approximately 20,000 pounds) will design the cargo compartment floor or necessitate use of undesirably large wheels or pads for support of the ACV vehicle on soft terrain. A means of self-unloading of non-mobile cargo from the lighter would eliminate requirements for use of either crane or fork lift in unloading the lighter and could well result in substantial savings in unloading time. Additionally, elimination of requiring either the cranes or fork lifts would facilitate rapid relocation of inland cargo transfer points and reduce the military inventory.

Provision for cargo positioning and self unloading by means of roller decks and winches similar to those employed in certain cargo aircraft configurations are arbitrarily ruled out because of the difficulty in controlling a heavy item of cargo with this gear in a rolling and pitching lighter as compared to that in a parked aircraft at level static rest upon the ground. Two possible means of satisfying the stated requirement are suggested.

a. The first is a traveling belt type flooring backed by spring-mounted rollers covering the width and length of the cargo space.

   It offers a means by which cargo can be moved rapidly and precisely and to the extent necessary to make room for succeeding cargo drafts as they are discharged over the side of the ship.

   It offers a rapid means of shifting the entire cargo load for center of gravity adjustment.

It offers a means of presenting cargo for fork lift unloading provided the cargo draft is properly faced when loaded aboard.

It permits progressive tie down to the traveling belt as cargo is loaded aboard the lighter with final tie down accomplished by belt locking after proper center of gravity adjustments are made.

b. The second is a traveling bridge hoist with travel the length and width of the cargo compartment and to an out-reach of six feet at one end. Safe working capacity of 10,500 pounds and lifting height sufficient to handle Conex containers are specified.

This system offers some improvement in hatch rate in that the cargo draft can be deposited in a general location within the lighter cargo compartment for further transverse and longitudinal spotting by the integral hoist.

It permits progressive tie down of the load as individual cargo drafts are received aboard the lighter if programmed loading is being accomplished.

It permits both longitudinal and transverse spotting of individual cargo drafts for weight and balance.

It permits positioning cargo for fork lift discharge with capability of rotating drafts as required to face them properly.

It permits direct discharge of cargo to a truck.

It permits unloading individual items to the ground, and if the lighter can be "walked" away from each draft, permits complete self-unloading.

Both the above solutions insure a certain independence of specialized shore unloading equipment. They broaden the opportunity for dispersal without increasing requirements for dispersal of special equipment. They increase the ease and frequency with which cargo transfer sites can be shifted when unloading is accomplished directly to truck transport.

Total decrease in lighter cycle time associated with the use of integral cargo handling gear is difficult to estimate. A combination of many factors could cut the unloading time of a self-discharging lighter in half. Such savings, together with increased hatch rates due to shorter hook cycle time, could be a profitable trade-off for decreased load capacity in the lighter caused by the weight of installed handling equipment.

2.(U) SHIPSIDE MANEUVER AND TIE-UP

Approach to, tie-up and casting off from a ship must be accomplished smartly and with a minimum loss of time if hatch rates are not to be depreciated. Controllability of the lighter and skill of the coxswain contribute much to this maneuver although the ability to handle lines freely and surely is equally important. Similar preciseness in handling the lighter is required if unloading techniques require fore and aft positioning of the lighter under the cargo draft. Two ACV design requirements are established by these shipside operations.

a. Fenders are required to protect the ACV lighter from damage against the side of the ship. This becomes a special design consideration as conventional fenders as used with other types of lighters may well impart localized damage to the light but otherwise adequate side structure of the ACV lighter.

   Large, relatively low pressure inflatable fenders built as integral part of the lighter are offered as a solution. Fenders are to be segmented to offer continued protection of the lighter in case of rupture of a single compartment. Like fender segments are to be used throughout the installation to allow interchangeability and as a means of reducing spare requirements.

b. A means is required for rapidly securing an ACV lighter alongside a ship while primary power is operating for control and cushioned stability under rough sea conditions.

   Lighter deck space fitted with mooring bitts or cleats well clear of all fans and propellers is the preferred means of satisfying this requirement. In case the configuration does not provide adequate space for the safe handling of mooring lines, an automatic means of establishing initial tie-up is required. In this case a rigid probe embodying an automatic engaging and controlled release latch is suggested for mating with a cone-like receptable streamed alongside the ship. Initial insertion must be achieved by precise maneuvering of the lighter or remote manual direction of the probe from within the cockpit.

   Once the initial mooring line is secured, machinery can be shut down and additional lines can be passed between lighter and ship for further security of the mooring.

3.(U) CARGO COMPARTMENT STRUCTURE

Relative motion between a lowering draft of cargo and a lighter is a combination of ship motion, lighter motion and the motion imparted by winch operation. This relative motion becomes increasingly difficult to anticipate and control as sea conditions worsen and must invariably result in occasional heavy impact of the cargo draft upon the lighter even when conditions are still favorable for continuation of the unloading operation. In off-loading vehicles vertical impact loads are absorbed in part through the resiliancy of the pneumatic tires and the spring suspension system of the vehicle. However, containerized and palletized cargo lack appreciable shock abosrbing structure and must be expected to impose full impact loads to the lighter through the runner-like structure that forms the supporting base of both container and pallet. This same relative motion between lowering cargo draft and lighter increases immeasureably the difficulty of exact positioning of a draft of cargo within the cargo space of the lighter and adds greatly to the safety hazards to personnel working within these spaces.

a. Tag lines attached to the cargo draft prior to hoisting it over the ship's side offer some means of controlling the swaying of the cargo draft as it is lowered into the lighter. Negative control of the draft can be achieved by taking up slack and controlling pay out of tag lines from around cleats on the lighter. Positive control is not believed to be a requirement.

b. Cargo space decking must be designed to sustain track or wheel and axle loading of mobile loaded military vehicles of gross weight equaling the rated overload capacity of the lighter. In addition, the structure must sustain the impact loads of containerized and palletized cargo drafts lowered into the lighter. The sides and upper rim of the compartment must likewise be able to sustain or be protected from the swaying impact of cargo drafts being lowered into the lighter from shipboard.

c. The ACV cargo deck design loads will probably result from accelerations that may be encountered in lighter movement over wavy water and impacts resulting from descent rate relative to the lighter at instant of contact. A reasonable estimate for an experimental first generation ACV, made without basis of recorded data or experience would

be 4 feet per second with the plane of the cargo draft base at a maximum angle of 5° to the plane of the lighter floor. Deformable absorption material in the form of renewable chafing strips around the edges of the compartment should provide an adequate buffer against swaying impact. Dunnage may be used on the deck in a similar manner to provide a deformable buffer.

The design of the ACV cargo compartment deck should be based upon experimental data obtained with its use in realistic LOTS operations, and account for its possible ability to provide cushioning of shock loads through use of partial lift power while being loaded.

4.(U) CARGO TIE-DOWN

Within operating height clearances, the ACV avoids reduction of operating speeds because of adverse sea and land route surface conditions. Cushion borne, the ACV is a relatively stable cargo platform, and when operated to minimize wave impact, may be expected to offer a smoother ride and to require less cargo restraint than a sea borne lighter underway in a heavy sea or during surf crossing. Partial air cushion support of an ACV while on the water should tend to dampen sea induced motion by interposing the compressible air cushion between the wetted bottom surfaces of the ACV and dynamic wave action. Safety considerations under adverse operating conditions do never-the-less establish a requirement for cargo tie-down restraint.

Cargo tie-down techniques and equipments employed in aircraft are probably applicable to ACV lighterage although the degree of restraint required in the ACV may be somewhat less. It is estimated that restraints of:

4 g forward
1 g rearward
1 g laterally
1 g vertically

are adequate for ACV lighterage operations. The employment of standard equipments and similar techniques as currently provided aircraft should prove adequate in the first generation ACV lighter for experimental test and serve as a basis for further design refinement.

Aircraft type seating and safety belt restraint are required for the crew and for use in troop transfer operations.

5. (U) VEHICLE RAMP

A requirement exists for an end ramp or set of adjustable treadways for the unloading ashore of mobile cargo operating under its own power. A ramp slope not exceeding 15° is required when the lighter is at static rest upon level ground

Compatibility with ramps of roll on and roll off shipping is a desirable feature.

6. (U) VEHICLE HANDLING GEAR

The ACV lighter must be able to discharge cargo at all inland transfer points that will support the operation of land contact cargo vehicles. Gear is required for wheeled or static support of the ACV lighter on soft soils that will support the operation of the rough terrain fork lift, tracked vehicles and wheeled vehicles equipped with desert tires. Foot print pressure of 15 pounds per square inch at design lighter gross weight and stability on a 15° slope are therefore required.

Clearance height of rigid vehicle structure of 24 inches on a flat surface is required to provide hard structure clearance of surface irregularities during unloading operations conducted on rough terrain.

Retraction of handling gear to a level above the hard structure of the vehicle is required.

Jacking points for use in jacking the ACV lighter off the ground with ground gear extended are required for gear maintenance and for occasional retrieval of out-of-commission vehicles.

Hoisting eyes for use in loading and unloading the ACV from sea transport are required.

a. A retractable wheeled gear offers advantages in towed mobility and in maintenance. It also offers the possibility of slowly moving the ACV lighter forward during possible self discharge of cargo to the ground; by means of the integral cargo handling equipments discussed previously. The wheeled gear is therefore suggested for primary consideration.

b. A flat plate footed tripod support is also suggested as possibly the simplest form of gear. In case it is used, lift off extraction from soft soils must be assured with a

means provided for breaking suction between the flat plate area and adhesive soils. The cloven hoof principle of area reduction is suggested for a rigid footing and peeling action in case an inflatable footing is used. As an alternate the primary lifting air supply may be diverted to exit from beneath the flat plate.

7. (U) PERSONNEL TRANSFER

Personnel may be considered a mobile, low density, fragile cargo. Except as they may be mobile loaded for roll off discharge by vehicle from a ship, they will be most expeditiously discharged over the side as individuals by ramp or cargo net. Safety in the operation is paramount. In the very likely absence of ramps, the cargo net must be used with the most dangerous portion of the descent occurring as the man transfers from the net to the lighter. The hazard in this transfer increases greatly with increasing relative movement between ship and lighter. Provision must be made so that this transfer can be accomplished expeditiously with provision for immediate clearance of the net and ready support by which the man can stabilize his position in the lighter.

Ladders must be provided for use by personnel in descending from the lighter top deck into the cargo compartment.

A relatively flat and fully unencumbered footing must be provided for personnel alighting on deck from a cargo net and as walkways to the ladders descending into the cargo compartment. Railing or other means of support must be available for ready use immediately after the individual man alights on deck.

A flat non-skid surface for personnel to alight upon can be provided when lifting fans are mounted in the plane of the deck. Protective screens or covers can be provided for fan duct inlets. Railings can be mounted sufficiently inboard to prevent interference with the cargo net and yet be near enough for the men to grasp readily as they alight from the cargo net.

All propulsive elements of the ACV lighter that can inflict bodily injury must be screened or protected by guard rails. Protective screening of propulsive gear is required to prevent damage from items of equipment dropped over the ship's side.

8.(U) STEVEDORE OPERATIONS

Stevedore operations must be held to a minimum aboard a lighter. There is a requirement for placing dunnage, steadying a cargo draft as it is being lowered into the lighter, detaching cargo hook and slings, and for cargo tie-down. Space must be provided within or exterior to the cargo space of the lighter to permit stevedore personnel to work efficiently and safely. Stevedoring in connection with unloading a lighter should be that required to hook up slings for cargo that is unloaded by hoist or crane and that required to operate cargo handling gear provided in the lighter.

Provisions for adequate cargo space within the lighter together with the provisions specified for cargo and personnel handling aboard the lighter are considered adequate to insure minimal stevedore requirements aboard the lighter and insure the working safety of all stevedore personnel that may be required.

D.(U) <u>SEA, TERRAIN AND METEOROLOGICAL FACTORS</u>

1. <u>SEA AND SURF FACTORS</u>

a. <u>Waves Classification and Definitions</u>

Waves of most concern in the design and operation of air-cushion vehicles are the wind-generated waves, normally referred to as "gravity waves." Waves are referred to as "sea" and "swell." Winds up to two knots produce ripples which die immediately with the wind. Winds over two knots produce gravity waves which progress with the wind and are referred to as "sea." With the cessation of the generating wind, friction and spreading cause the waves to be reduced in height and swells result. So-called tidal waves result from submarine earthquakes, volcanic eruptions and violent storms and are generally severe enough to halt any normal ocean operations. Such occurances are seldom and can reasonably be predicted or avoided if their origin is not in the vicinity of the area of operation.

The theoretical profile of the steepest possible wave approaches a ratio of wave length to wave height equal to 7:1. Ratios of length to height among the 2 to 5 foot waves, range from 10:1 to 125:1. A common ratio is on the order of 18:1. As the length to height ratio decreases, the crests become narrower and the troughs longer. At the ratio of 7:1, the wave becomes unstable and breaks at the crest, thus losing in height and steepness.

The condition of the sea is described in various ways, such as "energy" level, wave height, or "sea state." The "energy" (E) (given in units of square feet) of a fully aroused sea is defined mathematically by the agitating wind velocity (Vw) and is proportional to the actual energy imparted to the sea water by the wind (see References 8,9, and 10). The equation for E is:

$$E = .242 \ (Vw/10)^5 \ ft^2$$

The height (H) of a wave is the difference in elevation between the trough and crest. It is assumed that the crest height and the succeeding trough depth are equal as measured from the mean sea level. The mean or average wave height ($\bar{H}$) is the average of all wave heights during the period of time considered.

A generally accepted method of describing wave conditions is by the significant wave height ($\overline{H}_{33}$). The significant wave height is the average of the one-third highest waves, and is related mathematically to the "energy" level and to the average wave height as follows:

$$\overline{H}_{33} = 2.83 \sqrt{E}$$

$$\overline{H}_{33} = 1.6\,\overline{H}$$

The random variation of wave height has been shown empercially to follow the Raliegh distribution:

$$P = 1 - e^{-2F^2}$$

where P is the probability that H will not be exceeded and

$$F = \frac{H}{\overline{H}_{33}}$$

The probability of encountering waves higher than an arbitrary level, such as the significant wave height, have been computed from the Raliegh equation and verified by observations (References 8,10,11 and 12). From Table 1 in Reference 12 the following commonly used wave height to significant height ratios, computed from the above equations, are quoted:

Average wave height	0.625	$\overline{H}_{33}$
Average height of highest 10%	1.27	"
Height not exceeded more than 20% of time	0.89	"
" " " " " 10% " "	1.07	"
" " " " " 5% " "	1.25	"
" " " " " 3% " "	1.33	"
" " " " " 1% " "	1.58	"

From the above analysis the relationships shown in Figure III-10 can be computed. The "sea states" shown on Figure III-10 are commonly used ratings for describing sea conditions. They are related by definition to the generating wind velocity as shown. Figure III-10 then presents the significant wave height and the wave heights exceeded 1% and 10% of the time as functions of the generating wind velocity and/or sea state definition. The two upper curves on Figure III-10 mean that it can be expected that one out of every 100 or 10 waves, as the case may be, will exceed the values indicated by the respective curves.

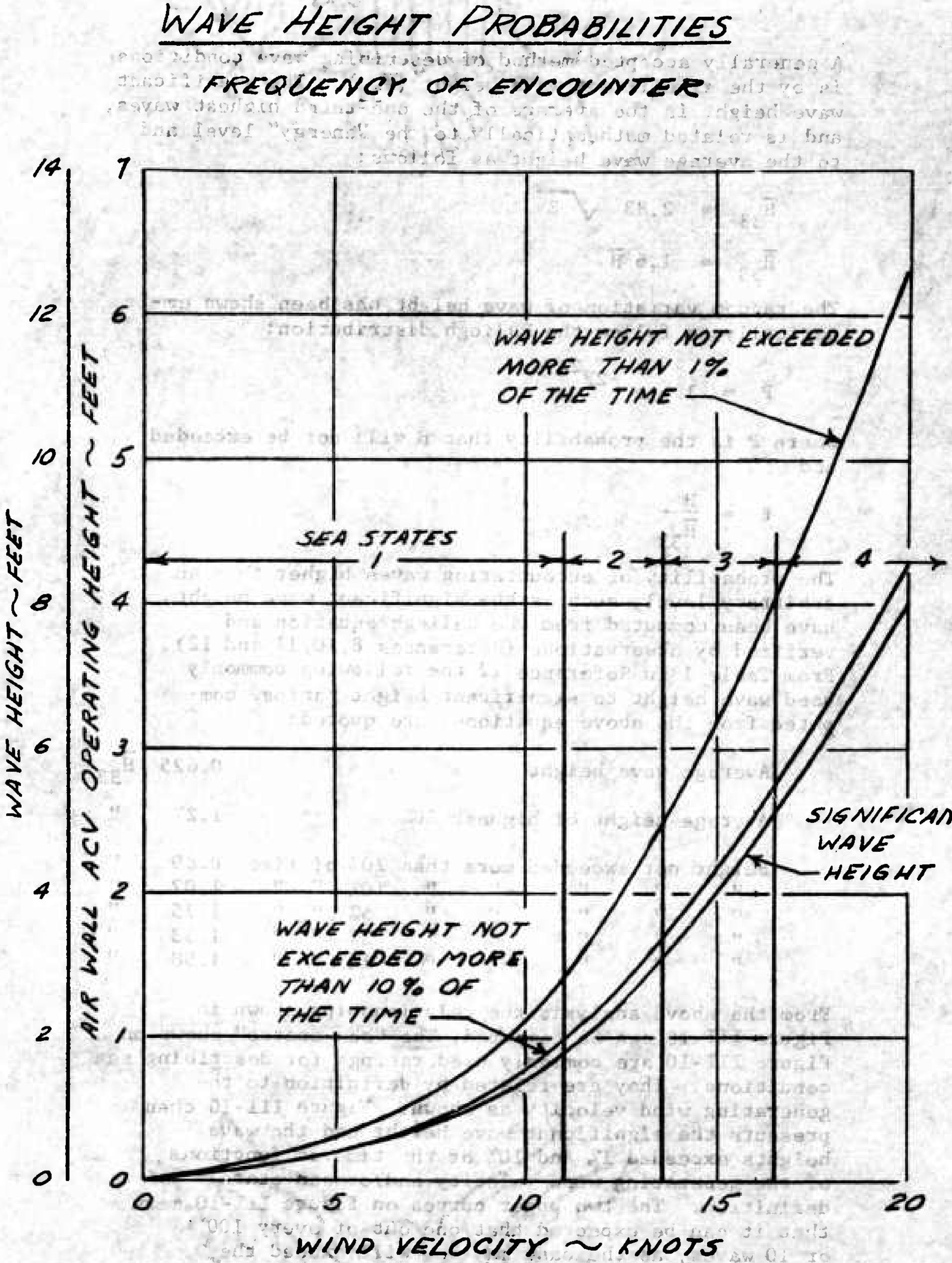


Figure III-10

If exceptionally high probabilities of not encountering a wave higher than a particular value are required, a different analysis should be used which takes into account the number of waves that will be encountered. Reference 10 derives the following equation:

$$P = e^{-e^{\frac{-H^2}{4E}}}$$

Where P is the probability that a wave no higher than H is encountered, and N is the number of waves encountered and can be computed as:

$$N = V_v \times 6080/\bar{\lambda} \times T$$

Where V_v is the vehicle velocity in knots, T is the trip time in hours and $\bar{\lambda}$ is the average wave length in feet, expressed by

$$\bar{\lambda} = .278\ V_w{}^2$$

A typical LOTS mission trip has been selected to indicate the wave heights which must be considered when high probabilities of not encountering waves greater than the operating height are desired. A trip time of 3.3 hours and a vehicle speed of 40 knots have been assumed. For these conditions and for the range of sea states of interest the relationships of significant wave height ($\bar{H}_{33}$), the most probable maximum wave height, the wave height exceeded only once in one hundred trips, and the wave height exceeded only once in one million trips were determined. The results are plotted on Figure III-11.

b. <u>Wave Data</u>

The preceding section described the mathematical methods used in defining the state of the sea and the methods used in predicting the randomness of wave height that can be expected for a given sea state. The probability of encountering any level of sea state varies greatly according to geographic location, season and local storm conditions and must be determined emperically from observations.

Reference 13 makes the following comments on deep water and surf wave height relationships. For waves with relatively large ratios of height to length in deep water (characteristic of the higher height, short period, wind waves) the surf breaker height

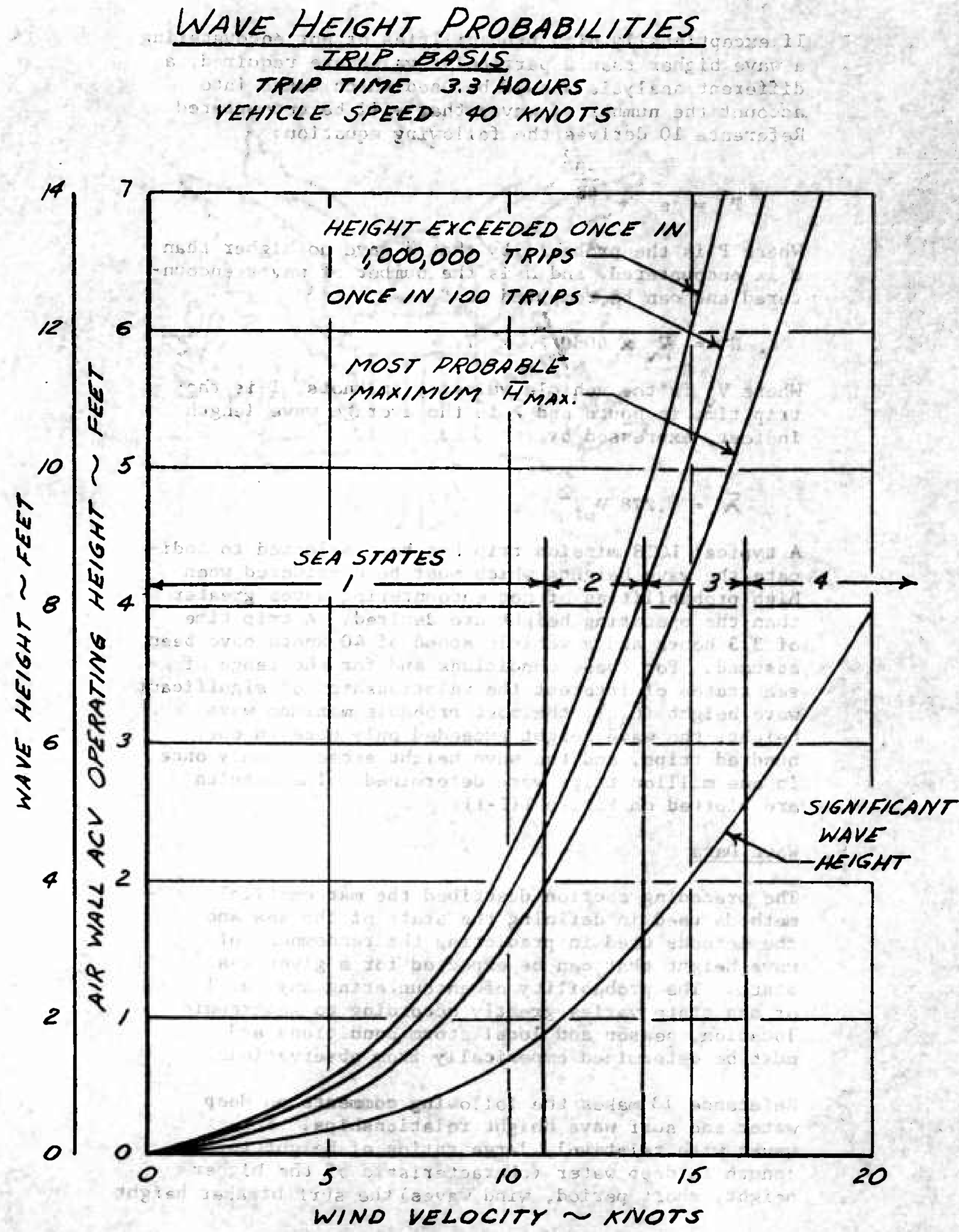


Figure III-11

is about the same as the deep water wave height. For waves with a small height to length ratio in deep water (characteristic of the relatively lower height, long period, swell) the breakers become much higher than the deep water height. A long, low swell almost unobservable in deep water may cause higher breakers than short period waves of much greater deep water height.

Figures III-12 and III-13 (data taken from References 12 and 14) present statistical deep water and surf wave height frequencies for two corresponding locations. As can be noted, high significant deep water wave heights are accompanied statistically by lower surf heights; whereas, the lower deep water wave heights are accompanied by higher surf heights than the deep water waves. As will be discussed later, wave heights on the order of 3.5 feet or greater at shipside will result in a degradation of the off-loading rate which can be maintained in calm sea conditions. At these deep water wave heights the surf conditions can be expected to be less severe than the deep water waves. Thus, it would appear that the deep water wave heights should be used as the predominate design consideration.

Wave data collected from all major ocean areas of the world were presented in Reference 15 and are tabulated in Table III-4 and summarized in Figure III-14. These data are further substantiated by Figures III-12 and III-13. Figure III-12 presents the year round average deep water wave heights for the U.S. North Atlantic Coast which approximates the world wide average indicated in Figure III-14. Figure III-15 from Reference 5 presents the deep water wave heights measured at Omaha Beach during June, July and August 1944. This, of course, was an optimum season and location and as would be expected, closely approximates the year round average of the most favorable locations and seasons shown in Figure III-14.

On an average year round basis there seems to be little variation between the northern and equatorial ocean regions when comparison is made on a latitude basis. Only the extreme southern latitudes show a significant increase in frequency of the higher waves as can be deduced from Table III-4.

In general, it can be said that the southern ocean areas (those below the equatorial belt) have the most frequent severe wave conditions. The southern ocean areas are the least important from a military standpoint as they involve only the southern half of South America, the southern tip of Africa, and the continent of Australia. The Equatorial Ocean areas can be said to have the most favorable wave conditions and represent areas of most military importance. The year round average curve shown in Figure III-14 includes data from ocean areas between Latitudes 60 N and 40 S.

c. Operating Height to Wave Height Relationship

Preliminary experience with models and experimental air-cushion vehicles of the air wall or peripheral jet type indicates that an operating height equal to one-half the wave height may be adequate to clear wave crests during cruise operations.

The particular dynamic characteristics and physical dimensions of each vehicle considered will have an important effect upon the operating height required. If the dynamic response of the vehicle is low enough (high inertia) and/or the wave lengths are short in respect to the vehicle length, an operating height equal to one-half the wave height appears reasonable for air wall type vehicles. If the dynamic response of the vehicle is high and the wave lengths are long with respect to the vehicle length, the vehicle will tend to follow the wave surface rise and fall; and, therefore, may require less than half the wave height as an operating height.

d. Effect of Seas on Cargo Transfer Operations

When sea conditions are calm, there is a maximum average hatch rate at which cargo can be unloaded from a cargo vessel to a lighter. The maximum hatch rate is dependent on the cargo ship boom equipment and the lighter characteristics. Unloading rate decreases as sea conditions become more severe, and when waves reach sufficient heights, unloading operations must cease. Data on the effect of wave height on ship cargo unloading rates have been obtained from Reference 5. These data include unloading rate and wave conditions for several wartime and peacetime amphibious operations. The data produces a broad band of wave heights at which the ship hatch rate initially degrades and at which unloading operations cease. The more significant causes for this spread of data are variations in human observations when estimating wave heights and the effects of different lighterage types on unloading rate.

The hatch rate expressed as a percentage of the calm sea hatch rate is shown on Figure III-16 in relation to wave height. No degradation in hatch rate is apparent

up to wave heights of 1.5 feet. Dependent upon the observer, the lighterage equipment and other factors, the initial hatch rate degradation is seen to occur at wave heights between 1.5 and 5.0 feet. Unloading operations are seen to cease when wave heights of 4.0 to 10.0 feet are encountered. Assume the left-hand edge of the data band presented on Figure III-16 represents wave height observations made by an observor who was actually recording average wave heights, and the right hand edge of the data band represents observation made by an observor who was actually recording the highest 10 percent of the waves, then by application of the appropriate factors previously presented for conversion of these data, significant wave heights would be closely approximated by the line designated as the "mean interpretation". For the purposes of this study the solid line drawn within the data band has been assumed. The design height of air cushion vehicles for the LOTS mission will be selected to permit operation at design payload capacity and design speed in seas characterized by 3.5 foot significant wave heights.

e. <u>Effect of Design Philosophy on Operating Height</u>

When considering operation of an air cushion vehicle over the open sea, the question arises whether operation should be planned for no wave impact, occasional wave impact, or repeated wave impact. The operating height requirement will be strongly sensitive to the design philosophy selected.

Vehicles which are not structurally capable of withstanding occasional wave impact are of questionable value because of such considerations as the following:

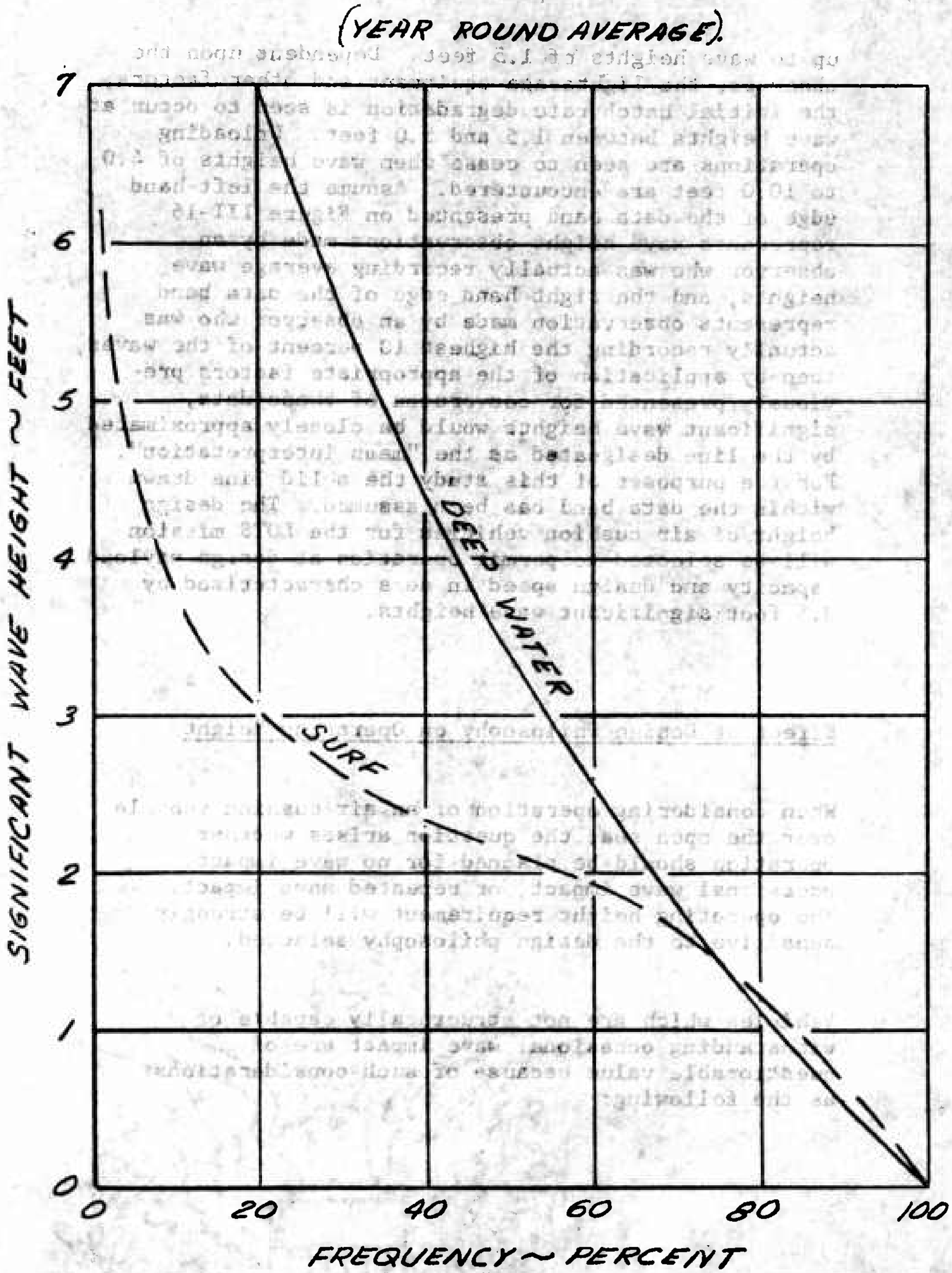


Figure III-12. Wave Height Frequency, North Atlantic Coast.

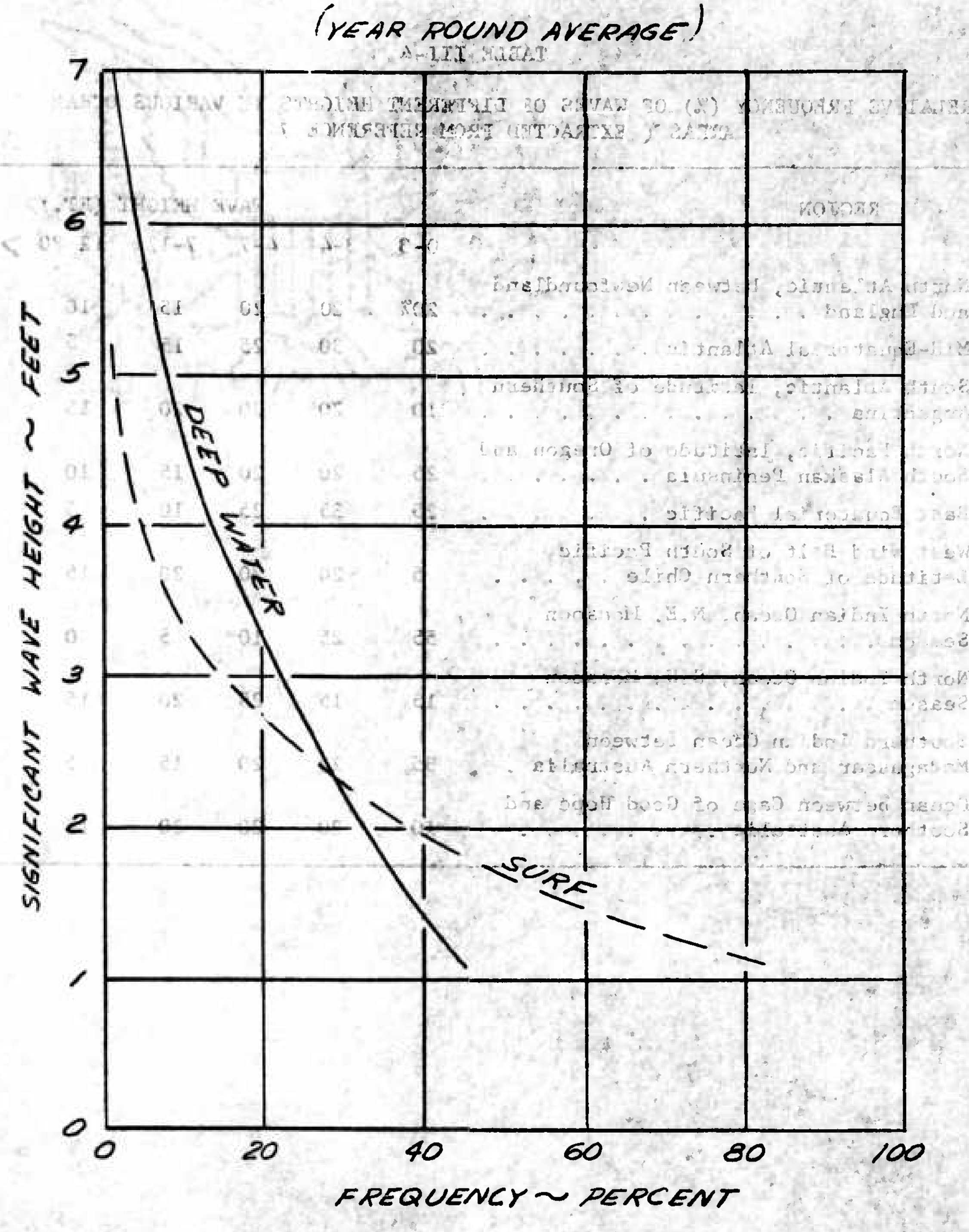


Figure III-13. Wave Height Frequency in Gulf of Mexico Near Mississippi Delta Area.

TABLE III-4

RELATIVE FREQUENCY (%) OF WAVES OF DIFFERENT HEIGHTS IN VARIOUS OCEAN AREAS (EXTRACTED FROM REFERENCE 7)

REGION	WAVE HEIGHT (FT.) 0-3	3-4	4-7	7-12	12-20	>20
North Atlantic, between Newfoundland and England	20%	20	20	15	10	15
Mid-Equatorial Atlantic	20	30	25	15	5	5
South Atlantic, latitude of Southern Argentina	10	20	20	20	15	10
North Pacific, latitude of Oregon and South Alaskan Peninsula	25	20	20	15	10	10
East Equatorial Pacific	25	35	25	10	5	5
West Wind Belt of South Pacific, Latitude of Southern Chile	5	20	20	20	15	15
North Indian Ocean, N.E. Monsoon Season	55	25	10	5	0	0
North Indian Ocean, S.W. Monsoon Season	15	15	25	20	15	10
Southern Indian Ocean Between Madagascar and Northern Australia .	35	25	20	15	5	5
Ocean between Cape of Good Hope and Southern Australia	10	20	20	20	15	15

BAND OF OCEAN WAVE HEIGHT FREQUENCIES

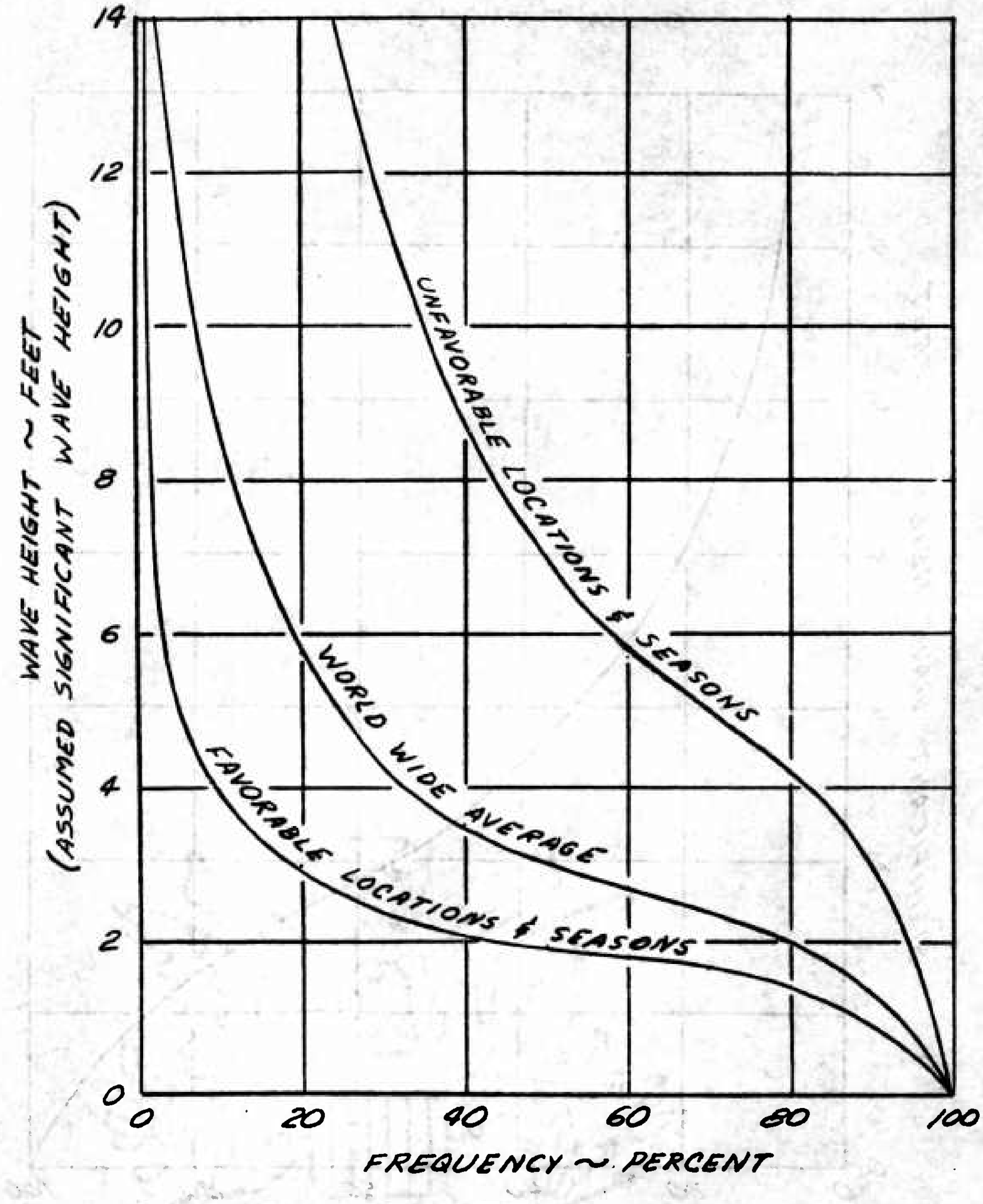


Figure III-14

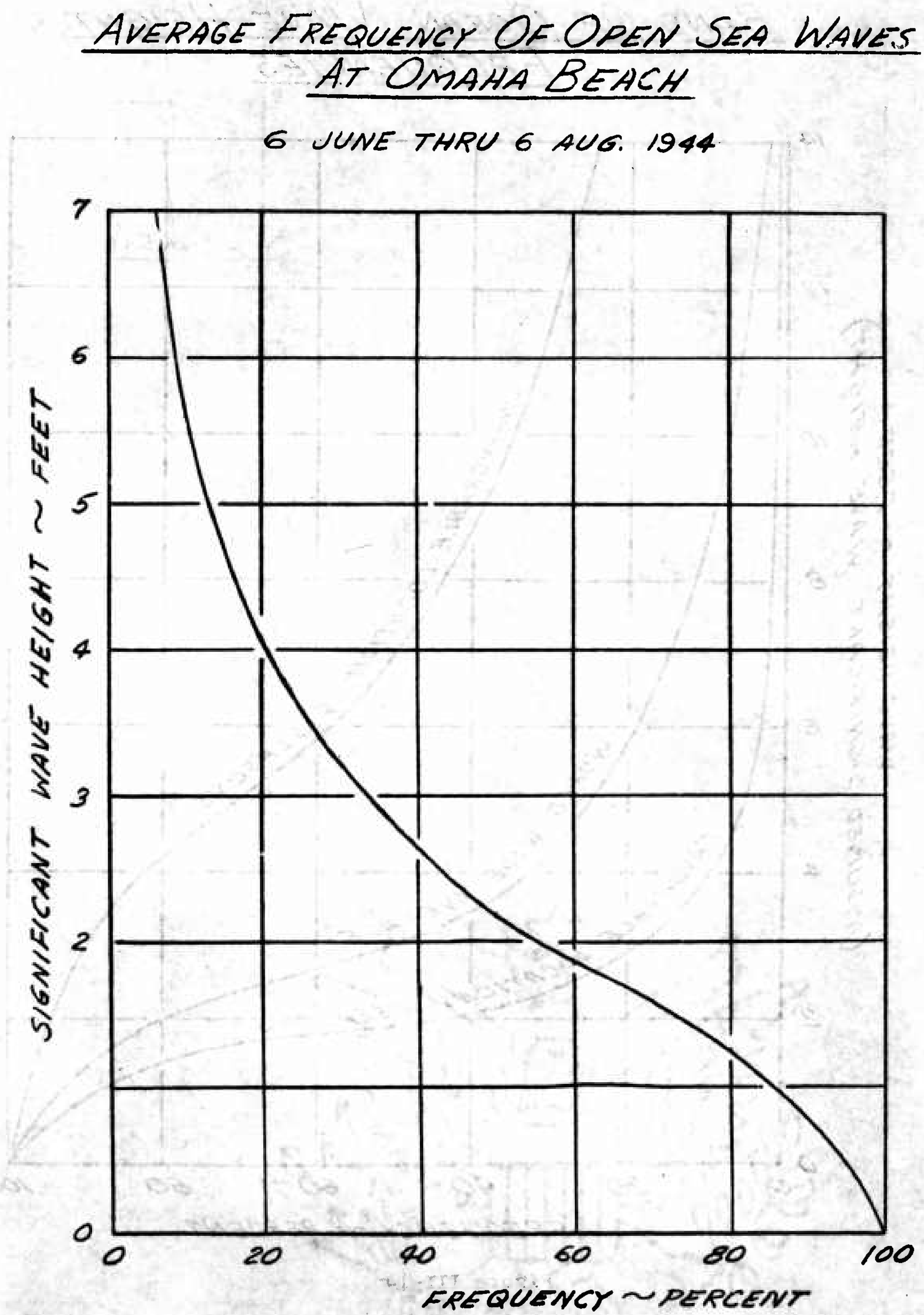


Figure III-15

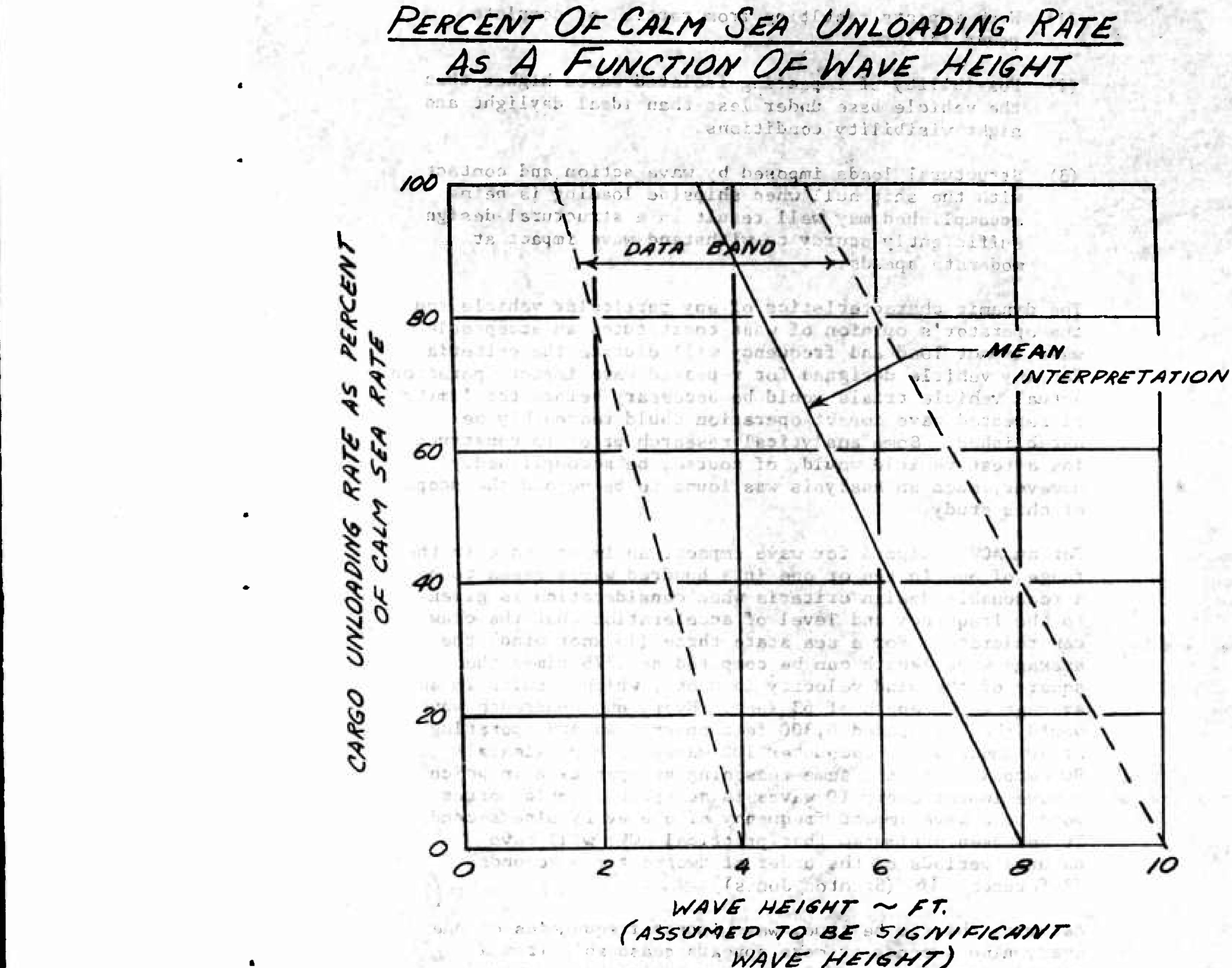


Figure III-16

(1) Wave impacts resulting from partial or complete power failure.

(2) Possibility of impacting isolated waves higher than the vehicle base under less than ideal daylight and night visibility conditions.

(3) Structural loads imposed by wave action and contact with the ship hull when shipside loading is being accomplished may well result in a structural design sufficiently sturdy to withstand wave impact at moderate speeds.

The dynamic characteristics of any particular vehicle and the operator's opinion of what constitutes an acceptable wave impact load and frequency will dictate the criteria for any vehicle designed for repeated wave impact operation. Actual vehicle trials would be necessary before the limits of repeated wave impact operation could reasonably be established. Some analytical research prior to constructing a test vehicle would, of course, be accomplished. However, such an analysis was found to be beyond the scope of this study.

For an ACV designed for wave impact, an impact rate in the range of one in ten or one in a hundred waves seems to be a reasonable design criteria when consideration is given to the frequency and level of acceleration that the crew can tolerate. For a sea state three (15 knot wind) the average wave length can be computed as .278 times the square of the wind velocity in knots, which results in an average wave length of 63 feet. Every one hundredth wave would then be spaced 6,300 feet apart. An ACV operating at 40 knots would encounter 100 waves in approximately 90 seconds. By the same reasoning an operation in which a wave impact every 10 waves is acceptable would correspond to a wave impact frequency of one every nine seconds. It has been estimated that practical ACVs will have natural periods on the order of two to three seconds (Reference 16 (Stanton Jones)).

Assuming this to be true, wave impact frequencies of one every nine seconds or more appears reasonable from a vehicle dynamics standpoint. The vehicle would have sufficient time to damp out after each wave impact. However, there is no assurance that the waves impacted will be evenly distributed. In fact, it is more likely that the higher waves in a given sea condition will appear in

periodic groups. Therefore, a design criteria of one wave impact in every one hundred waves has been selected for vehicles designed for wave impact operation.

The most severe sea condition in which cargo ships can off-load cargo at maximum hatch rate can be used as an upper design limit for ACV operating height with maximum design cargo. Figure III-16 indicates that maximum cargo ship off-loading rate can probably be maintained up to significant wave heights of 3.5 feet. Entering Figure III-10 at a significant wave height of 3.5 feet, it can be seen that wave heights greater than 5.5 feet will be encountered only 1% of the time and waves greater than 3.8 feet will be encountered 10% of the time. Therefore, a peripheral jet ACV design based on one wave impact in 100 waves requires a maximum design operating height of 2.8 feet when carrying the design cargo load.

Consider the design of a peripheral jet air-cushion vehicle for virtually no wave impact. That is to say, that one wave impact would seriously damage the vehicle by direct structural damage, or by deflecting it in such a way as to lose control with resulting damage due to improper impact with the water. For such a design philosophy it would be necessary to provide sufficient operating height capability to insure a very high probability of not impacting a wave. For a vehicle designed to cruise at 40 knots and having a typical mission trip time of 3.3 hours, Figure III-11 shows the wave heights and corresponding operating heights for three probabilities of wave encounter. Properly interpreted, the top curve indicates the wave height which can be expected to be exceeded only once in a million trips. The second curve indicates the wave height which can be expected to be exceeded but once in one hundred trips. The third curve shows the most probable maximum wave height which is essentially the average of the highest wave encountered on all trips. The operating height of peripheral jet ACVs defined as one-half the wave height is shown for quick reference.

If it is presumed that a million trips, each having 3.3 hours duration at 40 knots, over seas characterized by significant waves of 3.5 feet represents an adequate safety level for a vehicle designed for no wave impact, then it should be designed for a 5.4 foot operating height as can be deduced from Figure III-11. The data is, of course, not capable of telling on which trip such

a wave height will be exceeded. However, it seems rational to expect that unusual sea or weather conditions would warn of such increased wave activity so that some preventative measures could be taken.

The wave length of the one high wave must also be considered. If the high wave exhibits a wave length that is long with respect to the vehicle length, the vehicle will tend to follow the wave contour. The 10.8 foot, or greater, wave height posing possible wave encounter problems to the vehicle operating at 5.4 feet can exhibit wave lengths varying from a minimum of 76 feet to a more probable length of 220 feet, vehicles having less than 110 foot length would tend to follow the wave contour. The foregoing statements are predicated on a rudimentary analysis of the vehicle's dynamics.

Most probably, an operating height criteria falling between the two extremes discussed will prove to be practical. An operating height in excess of that predicted by a one in ten wave impact will be required for overland mobility. (See Section III 2.f.) Wave impact capability may result with little extra structural cost over that required by safety provisions for power failure and design considerations for loading at shipside.

It is concluded, therefore, that an overwater operating height permitting a wave impact frequency of one out of every 100 waves encountered in seas characterized by 3.5 foot significant waves provides reasonable and somewhat conservative criteria for first generation ACVs employed in LOTS operations. Modification of these criteria based on ACV operational experience is to be expected.

f. Conclusions

Based on the foregoing overwater operation analyses, it is concluded that an ACV planned for the LOTS mission should be designed to withstand repetitive wave impact at the rate of approximately one out of every 100 waves (one wave impact every 90 seconds). The vehicle should be designed to operate with design payload at design cruise speed in seas characterized by 3.5 foot significant wave heights (Sea State 3). These criteria result in a design operating height of 2.8 feet for the peripheral air wall vehicle.

The data, collected on a world wide basis, shown on Figure III-14 indicate that seas characterized by 3.5 foot significant waves, or less, can be expected 60% of the time. In favorable locations and seasons, such sea conditions can be expected almost 90% of the time.

2. TERRAIN FACTORS

a. Quantifying Terrain

The overland environment of the air-cushion vehicle is even more difficult to quantitize than the ocean characteristics. Soil types, flowing and stagnant water, natural and man-influenced vegetation, natural and man-made structures, all comprise the environment in which the air-cushion vehicle must operate or by-pass if true cross-country operation is to be expected. In Reference 15, Booz-Allen Applied Research, Inc. has presented a survey of the world-wide operating environment for the air-cushion vehicle. The resulting descriptions of the land environment are understandably more qualitative than quantitative. The numbers quoted in describing terrain and obstacles span broad ranges and are generalized over large geographic areas. The conclusions drawn as to desirable vehicle characteristics can be no more than generalized opinions. The fact that what appears to have been a fairly extensive survey of available geographic data could produce no more specific description of terrain and obstacles is considered to be indicative of the difficulty of the task.

Surveys and maps which provide the dimensional details necessary for this task are not known to exist. Maps with contour lines at three meter intervals are of little use in determining whether an ACV or a wheeled vehicle having clearance height of three feet and a certain angle of break capability could negotiate the described terrain.

The only plausible method of attacking this problem would be on a specific route basis. Several actual routes in various locales that might be used by tactical supply vehicles could be scouted and mapped in great detail. The traverse of these routes with existing vehicles could be physically accomplished, or at least analyzed in detail. From such route detail and the performance of known vehicles on such routes, the required performance characteristics of air-cushion vehicles on these routes might be more specifically determined. Generalized projection of typical terrain and ACV routes could be accomplished and serve as a guide in establishing overland air-cushion vehicle capability requirements.

Historically, the improvement in true cross-country mobility of any vehicle concept which is by nature dependent on the earth's surface for supporting its

weight has been accomplished in a step-wise fashion. Improvements in technology and mechanization have made gradual advances in mobility over unprepared terrain. A more meaningful and more specific method of determining the cross-country performance objectives for a first generation air-cushion vehicle might be to examine the currently desired performance improvements in conventional land transport vehicles and use these as minimum criteria for an air-cushion vehicle.

The inherent capabilities of air-cushion vehicles not obtainable in other more conventional land vehicles, or amphibians, are many. The ability to traverse any terrain profile that does not present obstacles and slopes beyond the capability of the air-cushion vehicle with absolutely no performance degradation because of the soil type or condition (mud, march, sand, snow, ice, water, etc.) is in itself a capability attainable with no other than truly air-borne vehicles. The advantage of such a capability in a military situation is immeasurable. Even if the terrain mobility capabilities of wheeled or tracked vehicles, when operated over good soil conditions, were just equaled by an air-cushion vehicle, its adverse soil capabilities should prove to make its existence in the inventory worthwhile.

b. Minimal Mobility Requirements

To determine the minimum overland capability requirements for an ACV, the minimum criteria for proposed cross-country transport vehicles, as outlined by the Transportation Corps, can be used. These criteria are listed in Table III-5 which was extracted from Reference 17. These criteria for improved transport vehicles were developed with wheeled or tracked vehicles in mind. However, they do represent what is considered by the Transportation Corps as a significant advancement in the mobility of what may be termed "surface transportation vehicles" in the combat zone.

An ACV vehicle which could meet these criteria would still exhibit overall mobility superior to wheeled or tracked vehicles, which also meet them, because the ACV suffers no degradation in performance due to adverse surface conditions and, therefore, should be a desirable addition to the inventory of transportation vehicles.

TABLE III-5

MINIMUM CRITERIA FOR PROPOSED CROSS-COUNTRY TRANSPORT VEHICLE

(from Reference 11)

PERFORMANCE ITEM	TANK M-48	CARRIER PERSONNEL FULL TRACK	TRUCK 2½TON M-34	MINIMUM CRITERIA FOR PROPOSED TRANSPORTATION COMMAND CROSS-COUNTRY TRANSPORT VEHICLES
GROUND PRESSURE (PSI)	10.2	7.1	35.0	A ground pressure to permit movement in soft soils comparable to the most mobile major tactical vehicles in the supported units.
ANGLE OF APPROACH (degrees)	90	90	40w/ winch 40/w/o	90
ANGLE OF DEPARTURE (degrees)	90	90	43	90
ANGLE OF BREAK (Maximum height of vertical obstacle the vehicle can negotiate at a 90° angle of intersection (inches)	36	26	20	26
GRADABILITY (%)	60	60	64	60
SIDE SLOPE LATERAL STABILITY (%)				Center of Gravity permitting 360° turn on 60% slope
TURNING RADIUS, OUTSIDE (feet)	Pivots in place	23	35	23
GROUND CLEARANCE (inches)	18	18	19½	18
CRUISING RANGE (miles)	100	120	350	300
MAX. LAND SPEED (MPH)	30	32	62	35
FORDABILITY (inches)	48	Floatable	72	Floatable
MINIMUM FREEBOARD LOADED (inches)	None	13	None	13
WATER SPEED (MPH)	None	4	None	7

Conversion of the minimum criteria of Table III-5 into design requirements for an ACV results in the following:

Normal operating height	-	26 inches
Gradability	-	60 %
Side slope capability	-	60 %
Turning radius (slow speed)	-	23 feet (ACV pivots)
Ground pressure	-	less than 1.9 psi (that of the Weasel)
Cruising range	-	300 miles
Cruise land speed	-	35 knots
Fordability	-	inherent
Bouyancy	-	bouyant
Minimum freeboard	-	inherently more than 13 inches when airborne
Water steering	-	positive
Water speed	-	7 knots

All of these characteristics appear to be well within the state-of-the-art for a practical ACV with the possible exception of the slope and gradability requirements. A wheeled or tracked vehicle capable of negotiating a 60% slope on solid dry ground will have less slope capability when soil conditions are less favorable. The ACV's slope capability is essentially independent of soil conditions. The overall mobility of an ACV with a slope capability of 25% may be comparable to a wheeled or tracked vehicle with a dry ground slope capability of 60%. ACV operational data is required to both define its applicable requirements and its capabilities.

c. Maneuvering Considerations

When ACV operation is being conducted over prepared routes, existing surface roads, lakes or surveyed streams, it should usually be possible to operate at reasonable cruise speeds since no obstructions higher than the normal operating height need be anticipated. The primary consideration in such operations would be the turning performance of the vehicle in relation to the expected turn radii of the route. A vehicle traveling at 35 knots which has a maneuver capability of .25 g's can turn in a radius of 435 feet. Such a requirement on route layout does not appear unreasonable.

Operation over unprepared and unscouted open country poses the problem of visually acquiring obstructions in sufficient time or distance so that a maneuver to detour, lift over, or stop can be accomplished. Limited initial research on terrain shadowing of obstructions is reported in Reference 18. The terrain used in the survey was

mildly rolling grassland near the coast of Maryland with no obstructions to visibility, such as tall grass, bushes or other foliage. These data present the distance at which 3.5 foot and 7.0 foot obstructions were visible as a function of observer height. The data are presented on Figure III-17 for two probabilities of observance.

Assume that the ACV will be operated over unprepared and unsurveyed terrain, as typified in Reference 18, 5% of the time. To establish a reasonable risk level, a 95% probability of obstruction visibility was selected. This results in a 99.75% probability of safe operation.

For an example, it is assumed that the ACV operator's eye is located 8½ feet above the structural bottom extremity of the vehicle. With the vehicle operating 3.5 feet above the ground the operator's line of sight originates 12 feet above the ground. Then from Figure III-17 it is seen that obstructions of 3.5 feet and higher are usually visible within 117 feet. This, of course, assumes that visibility is not impaired by vehicle structure, foliage or weather conditions. Permitting the vehicle to operate at 7 feet provides an increase in critical observation distance of 225 feet. These distances are based on a probability of observation of 95%.

Maximum safe operating speed for a vehicle operating at 3.5 and 7.0 feet above the ground has been computed as a factor of deceleration and lateral acceleration capability for various obstruction avoidance maneuvers. Allowance for operator search, acquisition and recognition time is required and is estimated as 3.0 seconds from Reference 19. An additional allowance for the operator to obtain control action effect is assumed to be 0.5 seconds. Determination was made of the relationship between acceleration capability and operating speed for the following maneuvers and the results are plotted on the corresponding figures:

(1) Vehicle stopped straight ahead - Figure III-18.

(2) Constant "g" 90 degree turn performed so as to prevent the vehicle centerline from proceeding beyond a line passing through the obstacle and perpendicular to the original path of travel of the vehicle - Figure III-19.

(3) Constant "g" turn so the vehicle centerline passes within 10 or 20 feet of the obstacle center - Figure III-20.

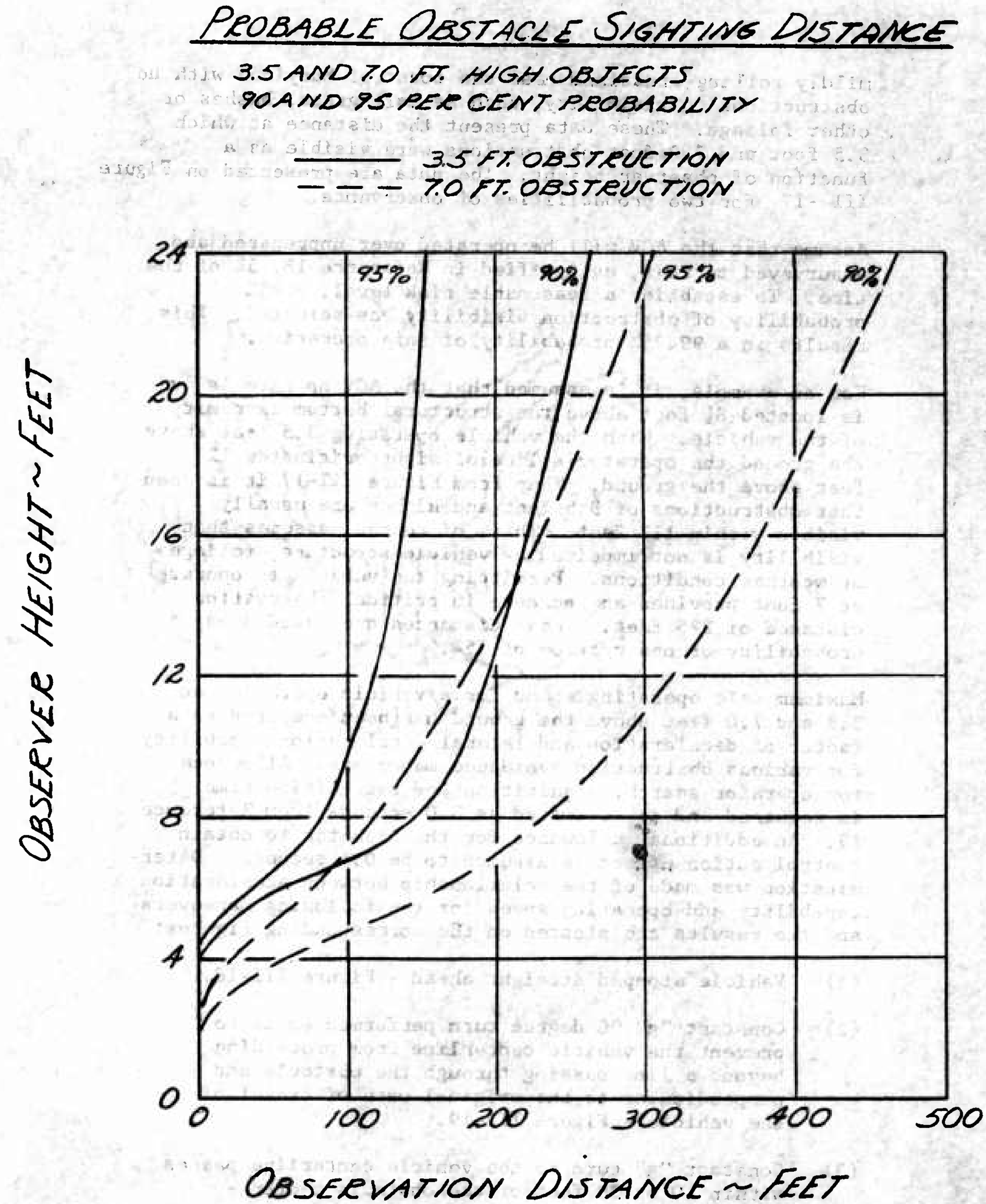


Figure III-17

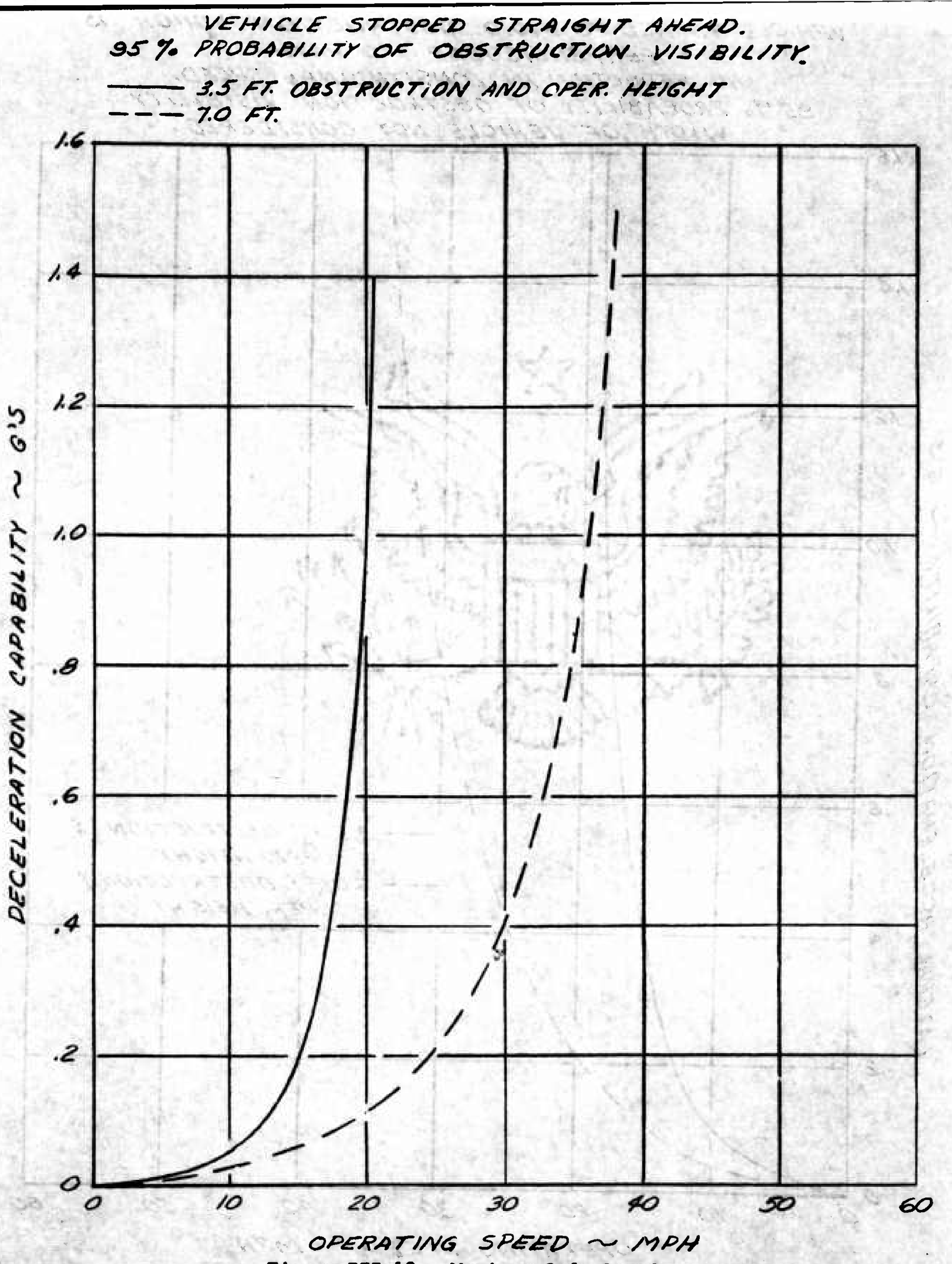


Figure III-18. Maximum Safe Speed.

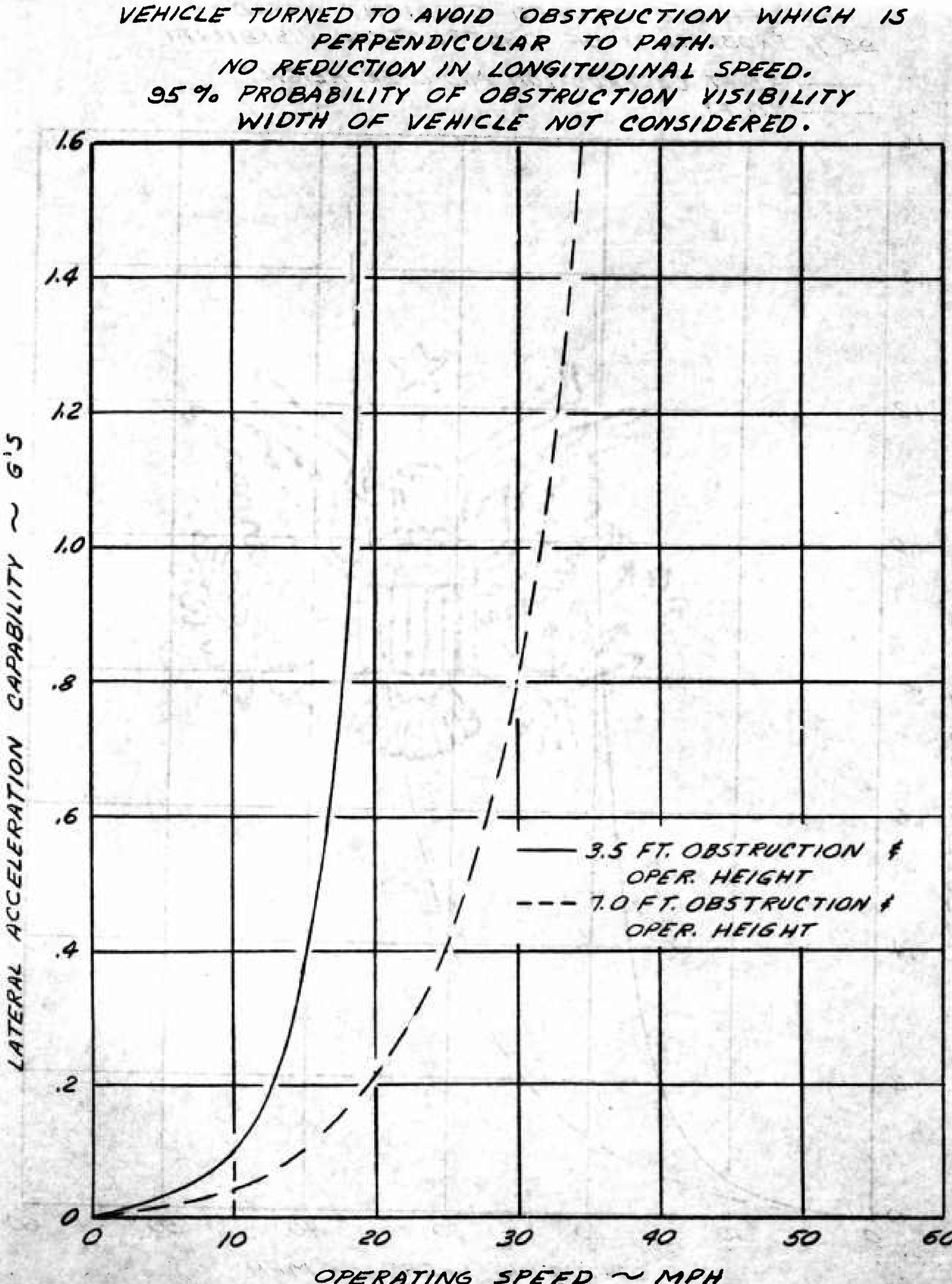


Figure III-19. Maximum Safe Speed.

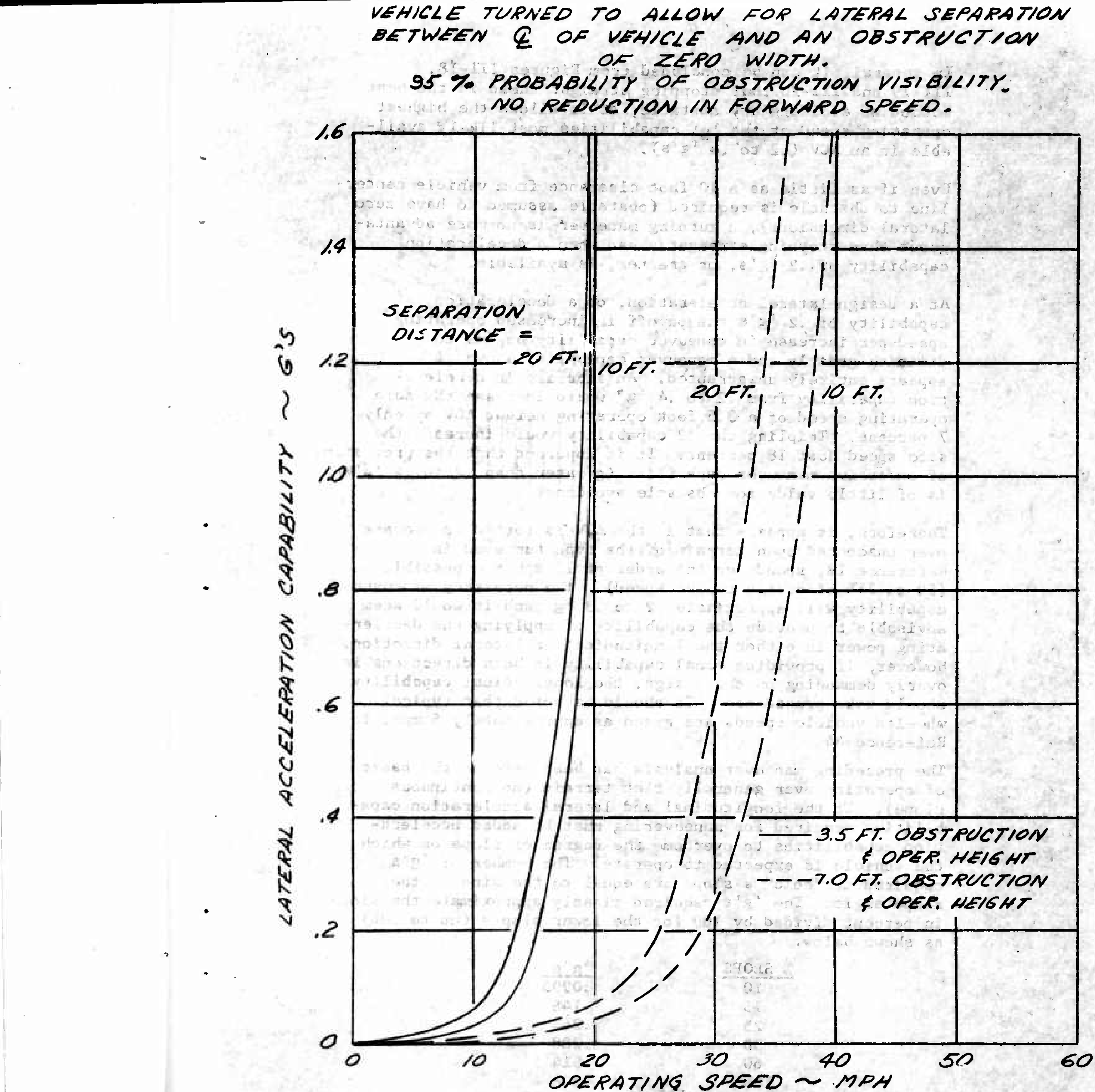


Figure III-20. Maximum Safe Speed.

In general, it can be concluded from Figures III-18, III-19 and III-20 that stopping straight ahead is the best method of avoiding any obstacle, as it allows the highest operating speed at the 'g' capabilities most likely available in an ACV (.2 to .4 'g's).

Even if as little as a 10 foot clearance from vehicle centerline to obstacle is required (obstacle assumed to have zero lateral dimensions), a turning maneuver is no more advantageous than stopping straight ahead when a deceleration capability of .2 'g's, or greater, is available.

At a design lateral acceleration, or a deceleration capability of .2 'g's the payoff in increased operating speed per increase in maneuver capability begins to diminish greatly and a maneuver capability above .4 appears entirely unwarranted. An increase in deceleration capability from .2 to .4 "g" would increase the safe operating speed of a 3.5 foot operating height ACV by only 7 percent. Tripling the .2 capability would increase the safe speed just 18 percent. It is apparent that the provision of excessive maneuver capability (greater than .2 to .4 'g's) is of little value for obstacle avoidance.

Therefore, it appears that if the ACV is forced to operate over unscouted open terrain of the type surveyed in Reference 18, speeds on the order of 15 mph are possible (50 to 25% of design cruise speed). The necessary maneuver capability will approximate .2 to .3 'g' and it would seem advisable to provide the capability of applying the decelerating power in either the longitudinal or lateral direction. However, if providing equal capability in both directions is overly demanding on the design, the longitudinal capability should take precedence. It should be noted that typical wheeled vehicle speeds are given as approximately 5 mph. in Reference 44.

The preceding maneuver analysis has been made on the basis of operation over generally flat terrain (no continuous slope). To the longitudinal and lateral acceleration capabilities required for maneuvering must be added acceleration capabilities to overcome the degree of slope on which the vehicle is expected to operate. The number of "g's required to "hold" a slope are equal to the sine of the slope angle. The 'g's required closely approximate the slope in percent divided by 100 for the lower slopes (up to 30%) as shown below:

% SLOPE	"g"s
10	.0995
15	.148
25	.243
30	.288
60	.514
100	.708

Therefore, the nominal .2"g's required for maneuvering and the approximate .10 to .15'g's required by a continuous slope of 10 or 15% dictate a total maneuver capability of .30 to .35"g's if it is desired to operate at the higher cross-country speeds on continuous down hill slopes. Operation on continuous down hill slopes would most probably be conducted at somewhat reduced speeds as is normally dictated by operator opinion even with conventional wheeled vehicles. Thus, a maneuver requirement of .25"g's to .30"g's would appear adequate.

d. Inland Obstructions to Mobility

Operation of any vehicle over unprepared terrain will be impaired by numerous obstructions. Dense forests, sheer cliffs, extreme slopes, and man-made structures are obstructions which no vehicle dependent upon the earth's surface for support can conceivably negotiate. Such obstructions must be by-passed or modified by construction effort.

Forestation will offer varying degrees of obstruction to the passage of vehicles dependent upon the spacing of the growth, the dimensions of the vehicle, and the maneuverability of the vehicle.

Terrain can limit the travel of vehicles dependent upon the steepness of the slope and the abruptness of change in slope. The vehicle will require enough installed propulsive power to overcome the slope and enough traction to exert that propulsive force. Wheeled or tracked vehicles are entirely dependent upon the soil for this traction. Coefficients of friction obtainable with ground contact vehicles are on the order of .5 under optimum soil conditions. A .5 coefficient of friction corresponds to a slope capability of 60% and appears to represent a limit for the slope capability of ground traction vehicles. The slope capability of ground contact vehicles, therefore, falls off rapidly as soil conditions become adversely affected by geophysical changes (mud, ice, and snow, or complete lack of moisture, as loose dirt and soft sand).

Air-cushion vehicles are not limited in slope capability by ground traction. The propulsive power installed is the only limit to their grade capability at low speeds. An air-cushion vehicle could negotiate limited length, up hill slopes in excess of its slope holding capability by approaching the slope at reasonably high speeds, thus using momentum plus propulsive thrust to overcome the slope.

Soil conditions affect the mobility of ground contact vehicles even on flat terrain. Wheeled or tracked vehicles bog down in wet or soft soil conditions because of their high ground pressures. The air-cushion vehicle inherently eliminates such difficulties.

From Reference 15, the following generalized world-wide geographical information is summarized.

> Throughout the world, 58 percent of the land has a slope gradient of less than 10 percent, 23 percent of the land has slopes between 10 and 30 percent and 19 percent of the land has slopes greater than 30 percent. Therefore, 81 percent of the world's land is possibly useful for ACV operation with slope capability of 30 percent. Of this 81 percent, 90 percent has elevations ranging from sea level to 3,000 feet and 99 percent has elevations less than 5,000 feet. Approximately 24 percent of the world's land surface is densely populated forest.
>
> On a world-wide basis, the widths of the majority of inland stream valleys at the mean water level are between 60 and 250 feet. It is estimated that about three-fourths of those of military significance are over 100 feet wide and that 95 percent are over 60 feet wide. Almost everywhere streams and rivers have vertical banks 5 feet high or steeply sloping banks (30-100% slope) 10 feet high.

Reference 15 also quotes the following clearance dimensions for man-made obstructions:

Ditches	2 - 10 feet deep 4 - 20 feet wide
Canal banks	10 feet high 100 percent slope
Dikes	2 - 20 feet high 30 - 50 percent slope
Walls	2 - 6 feet high 2 feet wide
Terraced cultivation	2 - 5 feet high 10 - 100 feet wide
Rail & road embankments	3 - 6 feet high 30 - 50 percent slope
Fallen trees, logs, rocks, etc.	1 - 3 feet high

e. <u>Beach Limitations</u>

The beach characteristics required for LOTS operations with conventional landing craft and amphibians are considerably more demanding than for air cushion vehicles. The air cushion vehicle imposes no criteria on the slope of the ocean floor at the surf line. Air cushion vehicles are truly amphibious and, thus, require no transfer of cargo on the beach as do conventional landing craft and, thus, do not require the large beach areas.

Both the conventional amphibians and the air cushion vehicles require inland access from the beach area. Both can utilize inland water routes if available. Dry land exit from the beach by either type vehicle can be restricted by steep slopes and width limitations. The air cushion vehicle will have advantages in areas where tidal water produces swamp-like formations where vehicles dependent upon marine propellers or amphibious tires would have great difficulty.

In general, it is concluded that more beach locations can be found which are acceptable for air cushion vehicle operations than for other vehicles used in the LOTS operation.

Reference 15 states that 80 percent of the world's beaches have maximum gradients less than 10 percent and about 90 percent have gradients less than 15 percent. This should not be confused with beach exit slopes which may be considerably greater. However, Reference 15 states that generally the steady gradients for near coast terrain are less than 15 percent.

f. <u>Conclusions</u>

The determination of operating height, maneuver capability, slope capability, and speed requirements for an ACV when operating over unprepared terrain is most difficult to quantify and recommend. However, based upon the minimum criteria for cross-country logistic vehicles, as given in Reference 17 and qualitatively modified by generalized world-wide terrain descriptions given in Reference 15, the following criteria are recommended:

Operating height	3 feet
Slope capability	15 - 25 percent
Maximum cruise speed	40 knots
Maneuver capability	.25 'g's

3. ENGINEER CONSTRUCTION

The preparation of temporary or permanent type roads for wheeled vehicles in the combat and supply zones is a necessary operation in many instances, due to adverse terrain. In operations where continued use of certain routes is expected, there is an economic advantage in constructing roadways.

The improvement in productivity of a vehicle which can be realized with improved roadway conditions is offset in the beginning by the road improvement or construction costs. However, continued use of the new or improved roadway generally results in a "payoff point", beyond which the cost per ton mile becomes less than it was for the unimproved or no-road operation. The time period to "payoff" can thus be considered the amortization period for the road costs. In military applications the time of use of a roadway will vary considerably with the progress of the military engagement and the tactical and strategic environment. The analysis presented in Section VII has been accomplished to show the influence of roadway costs on the overall operational cost of the various vehicles considered and to indicate the period of use at which roadway construction will begin to pay off for each vehicle.

All of the LOTS vehicles will be analyzed for operation over unprepared terrain, pioneer roads and hard surfaced roads. Most any vehicle can be operated at increasingly higher road speeds if the condition of the roadway is improved, which generally results in improved productivity of the vehicle (direct operating cost per ton mile). There is a countering effect to reduction of direct operating cost as the limit speed capability of the particular vehicle is approached. This results from increased maintenance requirements and other factors. However, for the tactical environment of LOTS operations, the maximum speed of the vehicles considered is seldom approached in overland operation.

Determination of the effort and cost of preparing terrain for wheeled vehicle or ACV use is difficult for anything other than a specifically defined set of circumstances. As can be seen in Tables III-6 and III-7 the effort required to construct a particular quality of road is widely variable according to the terrain characteristics. The information given in Tables III-6 and III-7 makes no allowance for weather conditions. Road construction in inclement weather conditions will require considerably more effort and elapsed time and, in some instances, will be almost impossible.

TABLE III-6

PIONEER COMBAT ROAD CONSTRUCTION

Net effective man-hours to clear, grub, strip and rough grade one nautical mile of pioneer combat road.

TERRAIN	ONE LANE 14 Ft. Wide	TWO LANE 22 Ft. Wide
Flat-prairie	1700	2300
Rolling	2300	2900
Hilly-forested	2900	3500

TABLE III-7

ROAD GRADING AND SURFACING

Net effective man-hours of engineer construction effort to grade and surface one nautical mile of road to the following standards:

One lane (12 - foot traffic lane plus 4 - foot shoulders)

Two lane (22 - foot traffic lane plus 4 - foot shoulders)

TERRAIN	ONE-LANE			DOUBLE LANE		
	GRADING ONLY	GRADING AND 6" GRAVEL	GRADING 6" GRAVEL AND 3"ASPHALT	GRADING ONLY	GRADING AND 6"GRAVEL	GRADING 6" GRAVEL AND 3" ASPHALT
Flat Prairie	2900	3800	14,500	4,000	5,500	21,600
Rolling	3900	4850	15,500	4,600	6,200	22,400
Hilly, forested	5400	6450	17,000	6,350	8,100	24,200
Mountain, forested no rock	9700	18,700	21,300	25,000	31,000	48,500
Mountain, some rock	16,000	22,500	32,800	42,000	52,500	68,500
Mountain, heavy rock	30,500	37,000	48,000	80,500	91,000	107,000

A detailed evaluation of weather conditions, terrain, soil, vegetation and the requirements for a specific route are necessary before any meaningful estimate can be made of the effort or cost required.

In the operational evaluation of the ACV it is desirous to evaluate the engineering support requirements if only on a comparative basis. The ACV does not require a hard surface, nor a truly "smooth" surface over which to operate as do most wheeled vehicles. Therefore, it does offer advantages in reduced engineer support and an attempt is made to evaluate this advantage.

From FM 101-10 Tables III-6 and III-7 have been extracted. Table III-6 estimates the "net effective man hours" of engineering effort required on the average to construct one nautical mile of a "pioneer type" combat road in three different types of terrain. Such a road is 14 feet wide for one lane traffic and 22 feet wide for 2 lane traffic. The effort estimate includes clearing and rough grading to the extent that reduced speed combat truck supply can be accomplished. In inclement weather, it would be expected that such a road would require continual maintenance and in severe weather may become almost unuseable.

Table III-7 estimates the "net effective man hours" of engineering effort required on the average to fine grade and surface one nautical mile of one and two lane first class roads intended for long term usage. The table shows the effort required to (1) smooth grade in preparation for, or in lieu of, gravel surfacing; (2) smooth grade and surface with six inches of gravel; and (3) smooth grade with six inches of gravel and surface with three inches of asphalt. The one lane road consists of a traffic lane 12 feet wide, with shoulders of four feet. The two lane road is a dual lane 22 feet wide, with shoulders of four feet.

The more permanent type military roads are constructed to a maximum grade requirement of 10 percent and pioneer roads are held to 10 percent wherever possible.

The data developed here is used in Section VII as the basis for determining and comparing overland operation costs for the vehicles of interest.

4. METEOROLOGICAL CONSIDERATIONS

a. Wind

Winds, particularly gusty winds, have been suggested as a cause for particular concern with respect to air cushion vehicle operation (Reference 15). It should be recognized at the outset that the effects of winds on the ACV are different only in magnitude than their effects on other vehicles. For example, operation of an automobile in very gusty wind conditions causes the driver considerable exercise in maintaining his vehicle in the proper lane. While gusty winds may prove somewhat more disturbing to the ACV operator than his counterpart in ground contact vehicles, rudimentary analysis indicates that the vehicle's track over the ground need not be seriously affected if the proper proportion of ACV directional stability and lateral control are provided.

For example, assume an ACV of 15 ton gross weight, with length 40 feet and height 6 feet is subjected to a gust of 40 knots at right angles to its path. The vehicle is considered to have neutral directional stability (no weather-cocking) and some contouring of the external shape so that something less than pure side flat plate drag will be experienced. Assume that the effective flat plate area is 75 percent of the actual. Our very severe assumed gust ($q = 5.4$ Lb/Ft^2) will produce a 960 pound force acting to laterally displace the vehicle. Further, it is assumed that the ACV operator does not obtain effective control response to counteract the gust for a full second. (Common figures for driver response in brake application are one-half second). The ACV will, therefore, laterally displace approximately 0.52 feet and attain a velocity of 1.03 feet per second in the lateral direction before countering control force is applied. Giving the ACV credit for a nominal .1 'g' lateral force to arrest the lateral motion results in the vehicle's unwanted lateral motion being stopped in .5 seconds and having traveled a total lateral distance of less than .9 feet (approximately 10 inches). Provision of moderate directional stability is desirable to minimize operator control motions. Due to the inertia of the vehicle, the gust produced lateral forces will not immediately alter the vehicle's heading. If the vehicle is too stable, directionally, it will weathercock into the gust and "drive up-wind". The converse is true if the vehicle is directionally unstable. Consideration of cross-winds in selection of ACV directional-lateral characteristics can, therefore, relegate their effects to an operational annoyance which is very tolerable. Complete removal of such annoyance is readily obtained with simple automatic controls.

. From the foregoing, it would be expected that the maneuver capability to counteract wind effects should be quite small. Assuming the same vehicle as before, it can be shown that a lateral maneuver capability of only .032 'g' is adequate to maintain both heading and track in a steady state 40 knot crosswind.

b. Precipitation

Rain, snow and fog will present visibility problems which are common to all vehicles, land or airborne. Higher speed vehicles suffer from loss in visibility even more than lower speed machines.

Icing problems resulting from rain and fog when the air temperature is at, or near, freezing are not peculiar to air cushion vehicles. The air cushion vehicle will encounter similar accumulations of ice from falling precipitation (on propellors and leading edges) as do aircraft and helicopters. The air cushion vehicle, because of continuous operation in the near vicinity of the ground, may induce its own precipitation from the water or snow already deposited on the ground. Minimization of self-induced environments is, however, thought possible by use of deflectors similar to those successfully developed by Vickers in England for ACV water spray deflection. This problem will be most severe during hover or slow speed operation. Operation over water, when the water temperature is above local freezing and the air is at or just below freezing, exhibits the same problems.

Air cushion vehicles when used in conditions where icing accumulation is likely, will probably need di-icing or anti-icing equipment similar to that installed on aircraft.

Reference 15 discusses the natural and induced environmental problems of air cushion vehicles in a qualitative manner and indicates in greater detail the most important design considerations.

E.(U) TRANSHIPMENT OPERATIONS

1. GENERAL

The transhipment of the required lighterage to the LOTS operational area has always posed a problem. Many methods are used dependent upon the type of lighter, the timing of the operation, the types of cargo vessels available for the operation, etc. When an overseas staging base exists in the vicinity of the intended operation and surprise is not essential, predeployment of lighterage to the staging base and subsequent predeployment to the area of operation can be accomplished during the operation build-up stage. When rapid reaction in isolated areas is

required, deployment of lighterage concurrent with the assault and supply shipping is most desirable. The ability to self-deploy or tranship with each cargo vessel enough lighterage to off-load that ship at its maximum hatch rate is certainly a desirable objective.

The special modified assault ships (APA's and AKA's) have provisions for transporting on their decks the assault and landing craft required for the amphibious assault. These ships are limited in number and must necessarily be kept in readiness for assault operations. The resupply of forces overseas must be handled by the more standard type cargo ships in the active or standby MSTS fleet.

In considering the deployment of lighterage for LOTS operations, self-deployment or transhipment on MSTS type ships, are the fundamental means to be studied.

2. SHIPPING CHARACTERISTICS

Each type of ship varies as to hull and hatch configurations and will accommodate deck or hold loading of vehicles in many different ways. Detailed study of the structure and equipment of each type vessel would be necessary before an exact determination of the loading of vehicles could be made. For the purposes of this study the hatch openings, the ship beam dimensions and the boom ratings of MSTS shipping, as given in References 1 and 20, have been used to determine the quantity of each type of lighter which can be transhipped on the decks of the MSTS ships.

Seven types of ships have been considered and are listed in table III-8. The number of each type in the MSTS fleet is given together with the internal hold cargo space. The total number of hatches for each ship type are also given. Most cargo vessels are equipped with one or two heavy lift booms. The number of heavy lift hatches is also given. A heavy lift hatch is one that is served by a boom of 30 ton capacity or greater. Hatches not served with heavy lift booms are presently served by 5 ton booms and burtoning gear. All boom capacities are quoted in long tons.

Table III-9 lists all of the hatches and ship beam dimensions corresponding to each hatch in a cumulative listing. Table III-10 shows the same information for the heavy lift hatches only. Knowing the dimensions of a particular vehicle, Tables III-9 and III-10 can be used to quickly determine the percentage of the hatch areas on which the vehicle can be placed. The hatch dimension given is the dimension fore and aft with respect to the ship.

TABLE III-8

CHARACTERISTICS OF MSTS SHIPPING

SHIP TYPE	NUMBER IN MSTS FLEET	CARGO SPACE Cu.Ft.	TONS OF MILITARY CARGO S. Tons	NUMBER OF HATCHES	NUMBER OF HEAVY LIFT HATCHES
C1-B	77	451,624	2,250	5	1
C1-M-AV1	7	227,730	1,140	4	2
C2	205	542,824	2,710	5	1
VC-2	257	456,525	2,280	5	2
C-3	139	736,850	3,680	5	1
C4-S-BS	12	711,580	3,560	7	2
C4-S-1a	26	736,723	3,680	7	2

Avg. Military Cargo Tonnage Per Ship = 2720 s. Tons

Avg. Number of Hatches Per Ship = 5

TABLE III-9

DISTRIBUTION OF MSTS HATCH SIZES

AND SHIP BEAM WIDTHS

HATCH DIMENSION (Ft.-In.)	← SHIP BEAM (Ft.-In.) → 76	71-6	69-6	63	62	60	50	TOTAL	SUM.	%
40-5							14	14	14	0.4
39-10	104							104	118	3.2
39-9½			139					139	257	7.0
37-3½			139					139	396	9.7
35-11					514			514	910	24.7
35-9½			139					139	1049	28.5
34-10				205				205	1254	34.1
32-4				205				205	1459	39.6
31-6						308		308	1767	48.0
30-0		36						36	1803	49.0
29-10	52			410				462	2265	61.5
29-9½			278					278	2543	69.1
29-3							77	77	2620	71.1
27-6		24						24	2644	71.9
26-10				205				205	2849	77.4
24-11					257			257	3106	84.4
23-11					514			514	3620	98.3
20-3		12						12	3632	98.6
20-1½							7	7	3639	98.7
20-0		12						12	3651	99.2
19-6	26							26	3677	99.8
9-0							7	7	3684	100.0
TOTALS	182	84	695	1025	1285	385	28	3684		
SUM.	182	266	961	1986	3271	3656	3684			
%	4.9	7.2	26.1	54.0	88.9	99.1	100.0			

TABLE III-10

DISTRIBUTION OF MSTS HEAVY LIFT HATCH SIZES AND SHIP BEAM WIDTHS

HATCH DIMENSION	← (SHIP BEAM (Ft. - In.) →									
(Ft.-In.)	76	71-6	69-6	63	62	60	50	TOT.	SUM	%
40-5							14	14	14	1.4
39-10	52							52	66	6.4
39-9½			139					139	205	20.0
35-11					514			514	719	70.1
34-10				205				205	924	90.1
31-6						77		77	1001	97.6
30-0		24						24	1025	100.0
TOTALS	52	24	139	205	514	77	14	1025		
SUM	52	76	215	420	934	1011	1025			
%	5.1	7.4	21.0	41.0	91.0	98.6	100.0			

3. TRANSHIPMENT OF LIGHTERAGE ON MSTS SHIPS

a. Lighterage characteristics

Table III-11 lists the characteristics of the three amphibious vehicles (LARC-5, 15 and BARC) and four hypothetical ACVs (two partially skirted air wall vehicles and two skirted vehicles). The dimensions and empty weights are used to determine the deck transhipment of the vehicles on MSTS ships. The speeds given are estimates of the average land and water speeds used in determining the number of lighters required to serve each hatch at maximum hatch rate.

b. Boom Limitations

All the vehicles considered herein have empty weights exceeding five tons. If no modifications are made to the five ton booms on MSTS ships in the time frame being considered, then the loading of lighterage vehicles on cargo vessels will be limited to the heavy lift hatches.

All of the ACVs and the LARC-5s and LARC-15s can be handled by the smallest heavy lift boom (30 long ton capacity) and, therefore, all can be loaded on any of the heavy lift hatches. All of the ACVs and the LARC-5s can be handled by booms of 10 long ton capacity if such booms are installed in place of the current five ton booms. The LARC-15 requires, at least, a boom of 15 long ton capacity and, therefore, is restricted to loading on only the heavy lift hatches.

The BARC, at an empty weight of 95 tons, exceeds the capacity of all the booms on MSTS ships. However, it could be loaded by dockside cranes and be "pushed off" the ship at the operational area. This technique has been demonstrated. Whether this technique is considered to be acceptable is, as yet, unknown. For the purposes of this study it has been assumed that the BARC can be loaded and unloaded from the heavy lift hatches. Thus, the BARC is not penalized by boom limitations to the same degree as the other lighterage types.

TABLE III - 11

CHARACTERISTICS OF LIGHTERS

PARAMETER	LARC 5	LARC 15	BARC	A PARTIAL SKIRT 63 x 30	B SKIRTED 40.8 x 20.4	C PARTIAL SKIRT 60 x 24	D SKIRTED 35x19
LENGTH (Ft.)	35	45	62.5	63	40.8	60	35
WIDTH (Ft.)	9	12.5	26.5	30	20.4	24	17.5
EMPTY WT. (S. Tons)	8.05	16.5	95	7.65	5.6	6.6	5.3
PAYLOAD (Nom.) (S. Tons)	5	15	60	10	15	10	15
AVERAGE WATER SPEED (Knots)	7	7	6	80	40	80	40
AVERAGE LAND SPEED (Knots)	4	4	3	15	15	15	15

c. Inhold Stowage

Of all the amphibians and ACVs considered here only the LARC-5 could be stowed below the main deck. All the other vehicles are too large to pass through the hatches without disassembly. For the purposes of the comparisons here no consideration was given to stowing the LARC-5 below decks. Stowage of the LARC-5 below deck would displace cargo and additional shipping would be required for this displaced cargo.

d. Deck Transhipment of Lighters

An estimate of the number of each type of vehicle which can be placed on the hatch area of each type of MSTS ship has been made and is shown in Table III-12 and III-13. Certain go, no-go rules were adhered to in determining the number of each type of vehicle which could be placed on each hatch position. The dimensions given are the hatch openings. Additional clear space is available around the hatch opening before deck equipment of super-structure is encountered. The exact amount will vary with each hatch and each ship. Therefore, if a vehicle or combination of vehicles did not exceed the hatch dimension by more than one foot (six inches over on each end) it was assumed that this extra space was available around the hatch opening. The full beam of the ship was considered available for stowage at each hatch, except the first (closest to bow) hatch where the actual deck width is considerably less than the maximum beam. Vehicles were permitted to overhang the side of the ship when such overhang did not exceed two feet on each side of the ship.

By averaging the estimated quantity of lighters that each ship can carry with respect to the number of ships of each type, the average numbers of lighters per ship were obtained and are presented in Tables III-12 and III-13.

e. Transhipment versus Productivity

The numbers of lighters required in the cycle to keep one hatch working at full capacity has been determined for the LARC-5, LARC-15 and BARC in the cost analysis section. The values used were taken from Section VI, for the 15 ton per hour hatch rate. By the same procedure the number of ACVs required in the cycle per hatch has been computed for a 7.2 ton per hour hatch rate.

TABLE III-12

ESTIMATE OF NUMBER OF AMPHIBIAN LIGHTERS
THAT CAN BE TRANSHIPPED ON DECKS OF MSTS VESSELS

SHIP TYPE & BEAM (Ft.-In.)	MAXIMUM LONGI-TUDENAL DIMEN-SION OF EACH HATCH (Ft.-In.)	NO. OF LARC 5	NO. OF LARC 5	NO. OF LARC 15	NO. OF LARC 5	NO. OF LARC 15	NO. OF BARC
C1-B	29-3	3	3	0	3	0	0
	31-6 *	3	0	2	0	0	1
60	31-6	3	3	0	3	0	0
	31-6	3	3	0	3	0	0
	31-6	3	3	0	3	0	0
		15	12	2	12	0	1
C1-M-AV1	20-1½	2	2	0	2	0	0
	40-5 *	5	0	3	0	3	0
50	40-5 *	5	0	3	0	3	0
	9-0	1	1	0	1	0	0
		13	3	6	3	6	0
C2-S-AJ	26-10	3	3	0	3	0	0
	32-4	3	3	0	3	0	0
63	34-10 *	6	3	2	1	0	1
	29-10	3	3	0	3	0	0
	29-10	3	3	0	3	0	0
		18	15	2	13	0	1
VC-2	24-11	2	2	0	2	0	0
	23-11	2	2	0	2	0	0
62	35-11 *	7	3	2	1	0	1
	35-11 *	7	3	2	3	2	0
	35-11	2	2	0	2	0	0
		20	12	4	10	2	1
C3-S-A2	35-9½	4	4	0	4	0	0
	29-9½	6	6	0	3	0	0
69-6	37-3½	7	7	0	7	0	0
	29-9½	6	6	0	6	0	0
	39-9½ *	7	2	3	0	1	1
		30	25	3	20	1	1
C4-S-B5	20-0	2	2	0	2	0	0
	27-6	6	6	0	6	0	0
71-6	27-6	6	6	0	6	0	0
	30-0 *	6	0	2	0	0	1
	30-0 *	6	0	2	0	0	1
	30-0	6	6	0	6	0	0
	20-3	4	4	0	4	0	0
		36	24	4	24	0	2

TABLE III-12

ESTIMATE OF NUMBER OF AMPHIBIAN LIGHTERS
THAT CAN BE TRANSHIPPED ON DECKS OF MSTS VESSELS

.......(Continued)

SHIP TYPE & BEAM (Ft.-In.)	MAXIMUM LONGITUDENAL DIMENSION OF EACH HATCH (Ft.-In.)	NO. OF LARC 5	NO. OF LARC 5	NO. OF LARC 15	NO. OF LARC 5	NO. OF LARC 15	NO. OF BARC
C4-Sp1a	19-6	2	2	0	2	0	0
	29-10	6	6	0	6	0	0
76	39-10	8	8	0	8	0	0
	39-10 *	8	3	3	1	1	1
	39-10	8	8	0	8	0	0
	39-10*	8	3	3	1	1	1
	29-10	6	6	0	6	0	0
		46	36	6	32	2	2
AVERAGE NUMBER OF LIGHTERS CARRIED PER SHIP							
10 TON MIN. BOOM CAPACITY ASSUMED		22.0	16.3	3.1	13.9	1.0	1.0
5 TON MIN. BOOM CAPACITY ASSUMED		8.9	3.6	3.1	1.0	.3	.9

* Indicates Heavy Lift Hatches

TABLE III-13

ESTIMATE OF NUMBER OF ACV LIGHTERS

THAT CAN BE TRANSHIPPED ON DECKS OF MSTS VESSELS

SHIP TYPE & BEAM WIDTH (Ft.-In.)	MAXIMUM DIMENSIONS OF EACH HATCH (Ft.-In.)	ACV PARTIAL SKIRT (63x30)	ACV SKIRTED (40.8x20.4)	ACV PARTIAL SKIRT (63x24)	ACV SKIRTED (35x19)
C1-B	29-3	0	1	1	1
	31-6 *	1	1	1	1
60	31-6	1	1	1	1
	31-6	1	1	1	1
	31-6	1	1	1	1
		4	5	5	5
C1-M-AV1	20-1½	0	1	0	1
	40-5 *	0	2	0	2
50	40-5 *	0	2	0	2
	9-0	0	0	0	0
		0	5	0	5
C2-S-AJ	26-10	0	1	1	1
	32-4	1	1	1	1
63	34-10 *	1	1	1	3
	29-10	1	1	1	1
	29-10	1	1	1	1
		4	5	5	7
VC-2	24-11	0	1	1	1
	23-11	0	1	1	1
62	35-11 *	1	1	1	3
	35-11 *	1	1	1	3
	23-11	0	1	1	1
		2	5	5	9
C3-S-A2	35-9½	1	1	1	2
	29-9½	1	1	1	2
	37-3½	1	1	1	4
69-6	29-9½	1	1	1	2
	39-9½ *	1	2	1	4
		5	6	5	14
C4-S-B5	20-0	0	1	0	1
	27-6	0	1	1	2
	27-6	0	1	1	2
71-6	30-0 *	1	1	1	2
	30-0 *	1	1	1	2
	30-0	1	1	1	2
	20-3	0	1	0	2
		3	7	5	13

TABLE III-13

ESTIMATE OF NUMBER OF ACV LIGHTERS

THAT CAN BE TRANSHIPPED ON DECKS OF MSTS VESSELS

(Continued)

SHIP TYPE & BEAM WIDTH (Ft.-In.)	MAXIMUM DIMENSIONS OF EACH HATCH (Ft.-In.)	ACV PARTIAL SKIRT (63x30)	ACV SKIRTED (40.8x20.4)	ACV PARTIAL SKIRT (63x24)	ACV SKIRTED (35x19)
C4-S-1a	19-6	0	1	1	1
	29-10	1	1	1	2
	39-10	1	3	1	4
76	39-10 *	1	3	1	4
	39-10	1	3	1	4
	39-10 *	1	3	1	4
	29-10	1	1	1	2
		6	15	6	21
AVERAGE NO. OF LIGHTERS CARRIED PER SHIP					
10 TON MIN. BOOM CAPACITY ASSUMED		3.6	5.6	5.0	9.4
5 TON MIN. BOOM CAPACITY ASSUMED		1.4	1.8	1.4	4.2

* Indicates Heavy Lift Hatches

The estimated average number of lighters that can be carried on each MSTS ship can be expressed as a percentage of the number of lighters required to service the five hatches of the average ship at a hatch rate of 15 tons per hour and 7.2 tons per hour. This was done for varying ship-to-shore distances, with the inland distance held at five nautical miles for all cases. The transshipment problem is then measured by the number of ships required to tranship sufficient lighterage to service one cargo ship. This value can be simply computed as the ratio of lighters required per ship to lighters transhipped per ship. The data for the lighterage transhipment ratio is presented in graphic form on Figures III-21 and III-22 for the vehicle combinations of most interest and an assumed hatch rate of 15 tons per hour.

From Figures III-21 and III-22 the relative transhipment problems of the various lighters can be compared. Both figures indicate that the amphibians pose a rapidly increasing transhipment problem for the greater ship-to-shore distances to be anticipated during future LOTS operations.

As previously indicated, the missile and nuclear threat will probably force the operation to station ships further out to sea, or to disperse them at much greater separation distances along the shoreline. The nominal three mile ship-to-shore distance that is dictated by the performance of current waterborne lighterage will, therefore, be substantially increased. For ship-to-shore distances of 20 to 30 miles or greater, even the larger planform air wall vehicles pose substantially less of a transhipment problem than the currant Army amphibians. At the shortest ship-to-shore distances a skirted vehicle can be selected which will pose no greater transhipment problem than the amphibians. It is quite apparent that the number of ACVs required is considerably less sensitive to increasing operational distance than the much slower amphibians and this fact manifests a strong influence on their relative transhipment problems at the greater distances.

The transhipment problem that could be expected if the minimum boom capacity of the MSTS ships were increased to 10 long tons and the hatch rate remained the same as today is shown in Figure III-23. The transhipment situation as it now exists with five long ton booms and the 7.2 short tons per hour hatch rate is shown on Figure III-24.

NUMBER OF SHIPS REQUIRED TO TRANSHIP A SUFFICIENT QUANTITY OF LIGHTERS TO SERVICE ONE 5 HATCH SHIP

HATCH RATE - 15 S.TONS/HR., LAND DISTANCE - 5 N.MI., DECK LOADING OF LIGHTERAGE ONLY; MINIMUM BOOM CAPACITY ASSUMED TO BE 10 LONG TONS; LARC-15'S AND BARC'S ASSUMED TO BE LOADED ON HEAVY LIFT HATCHES ONLY

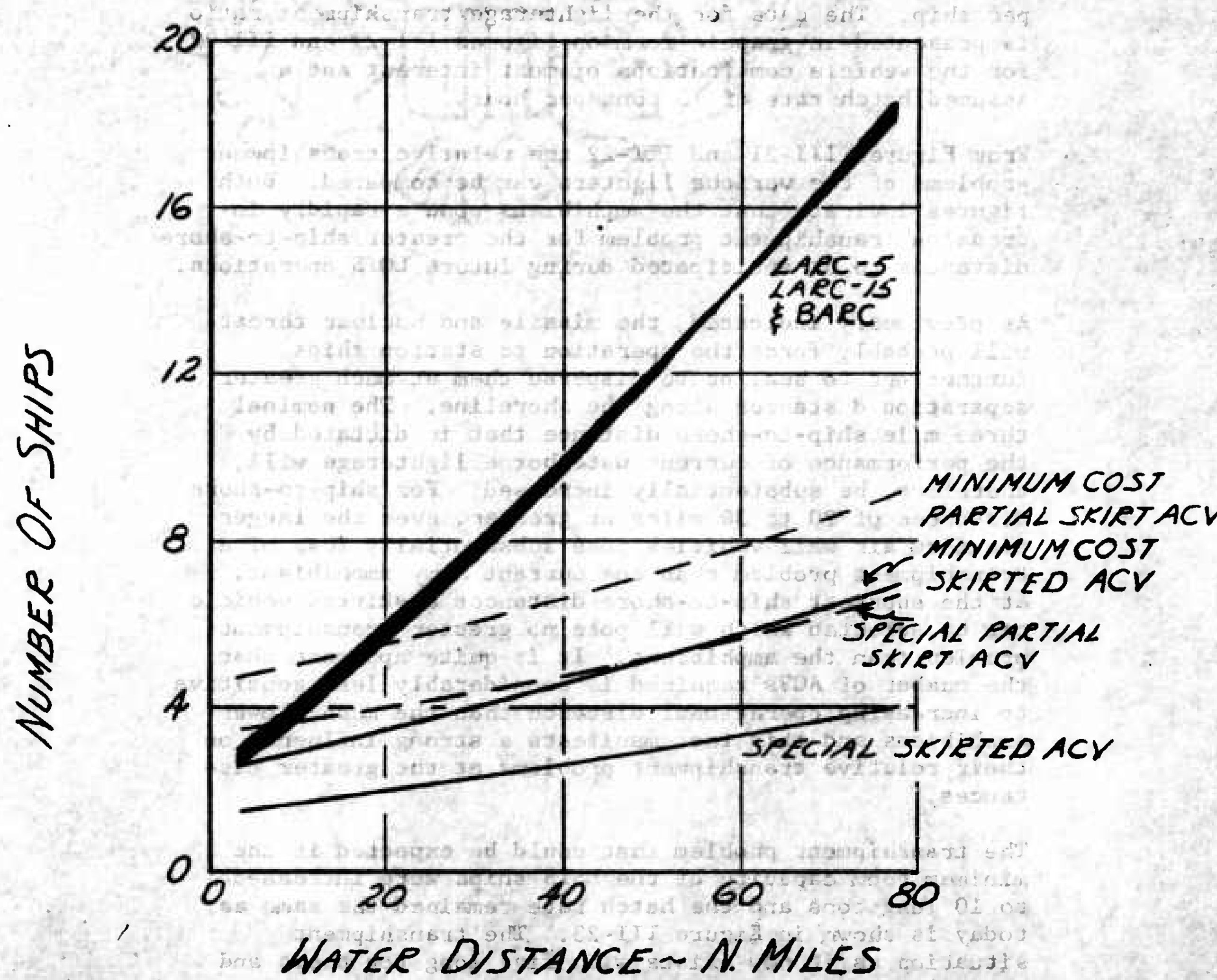


Figure III-21

NUMBER OF SHIPS REQUIRED TO TRANSHIP A SUFFICIENT QUANTITY OF LIGHTERS TO SERVICE ONE 5 HATCH SHIP

HATCH RATE = 15 S. TONS/HR., LAND DISTANCE = 5 N. MI.
DECK STOWAGE OF LIGHTERS ONLY
MINIMUM BOOM CAPACITY ASSUMED TO BE 5 LONG TONS, THEREFORE ALL LIGHTERAGE MUST BE LOADED ONTO HEAVY LIFT HATCHES ONLY

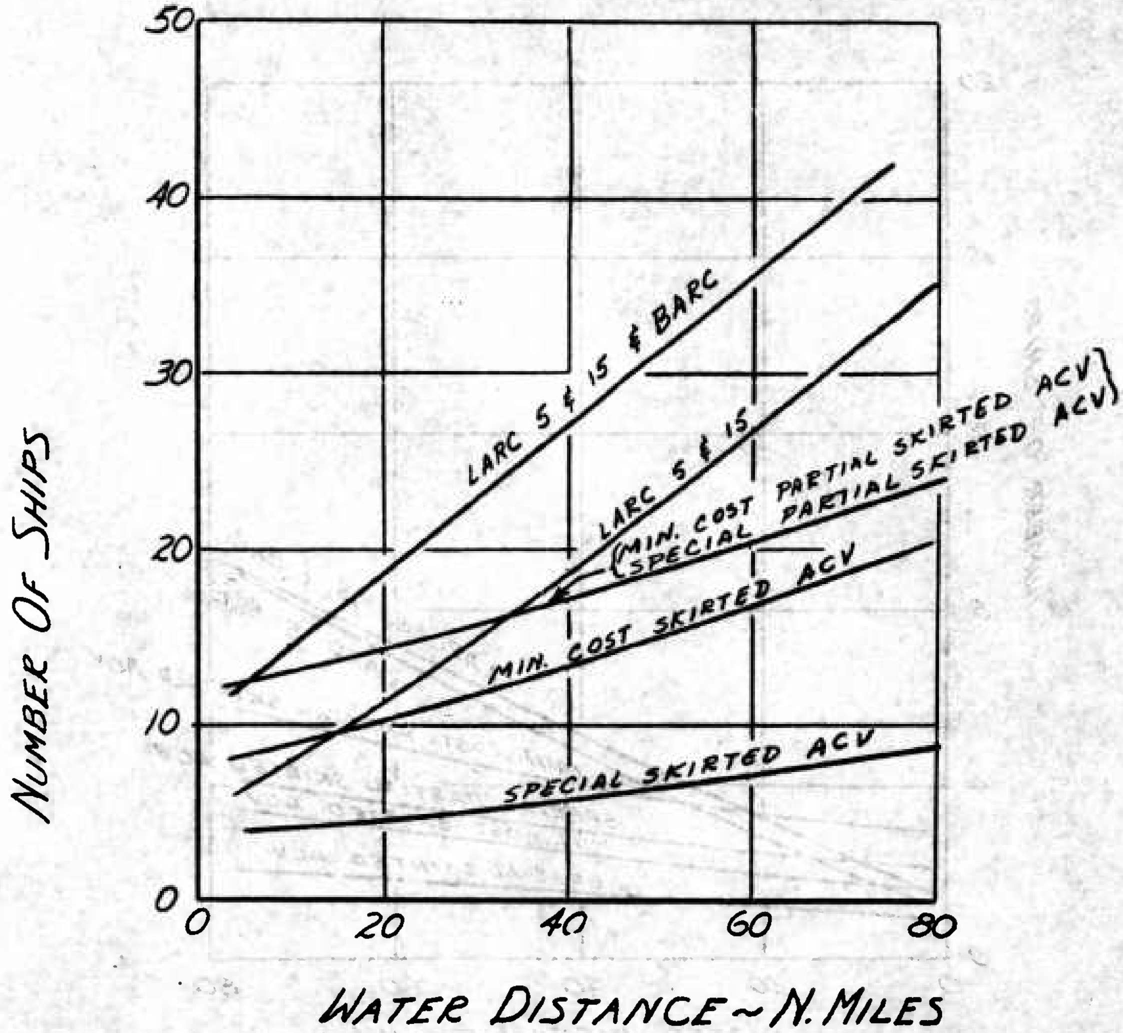


Figure III-22

NUMBER OF SHIPS REQUIRED TO TRANSHIP A SUFFICIENT QUANTITY OF LIGHTERS TO SERVICE ONE 5 HATCH SHIP

HATCH RATE = 7.2 S. TONS/HR., LAND DISTANCE = 5 N.MI.
DECK LOADING OF LIGHTERAGE ONLY
MIN. BOOM CAPACITY ASSUMED TO BE 10 LONG TONS
LARC 15'S AND BARC'S ASSUMED TO BE LOADED ON HEAVY LIFT HATCHES ONLY

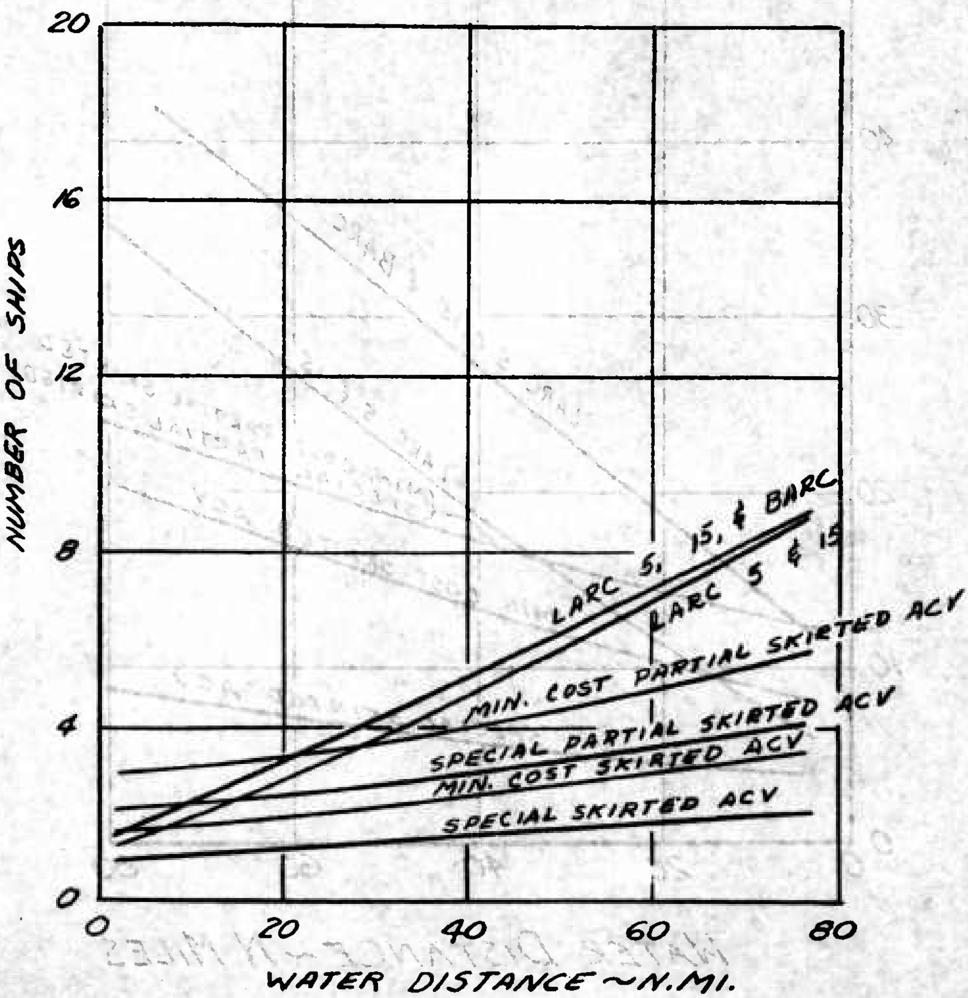


Figure III-23

NUMBER OF SHIPS REQUIRED TO TRANSHIP A SUFFICIENT QUANTITY OF LIGHTERS TO SERVICE ONE 5 HATCH SHIP

HATCH RATE = 7.2 SHORT TONS/HR.
LAND DISTANCE = 5 N.MI.; DECK LOADING OF LIGHTERAGE ONLY; MINIMUM BOOM CAPACITY, ASSUMED TO BE 5 LONG TONS
LIGHTERAGE MUST BE LOADED ON HEAVY LIFT HATCHES ONLY

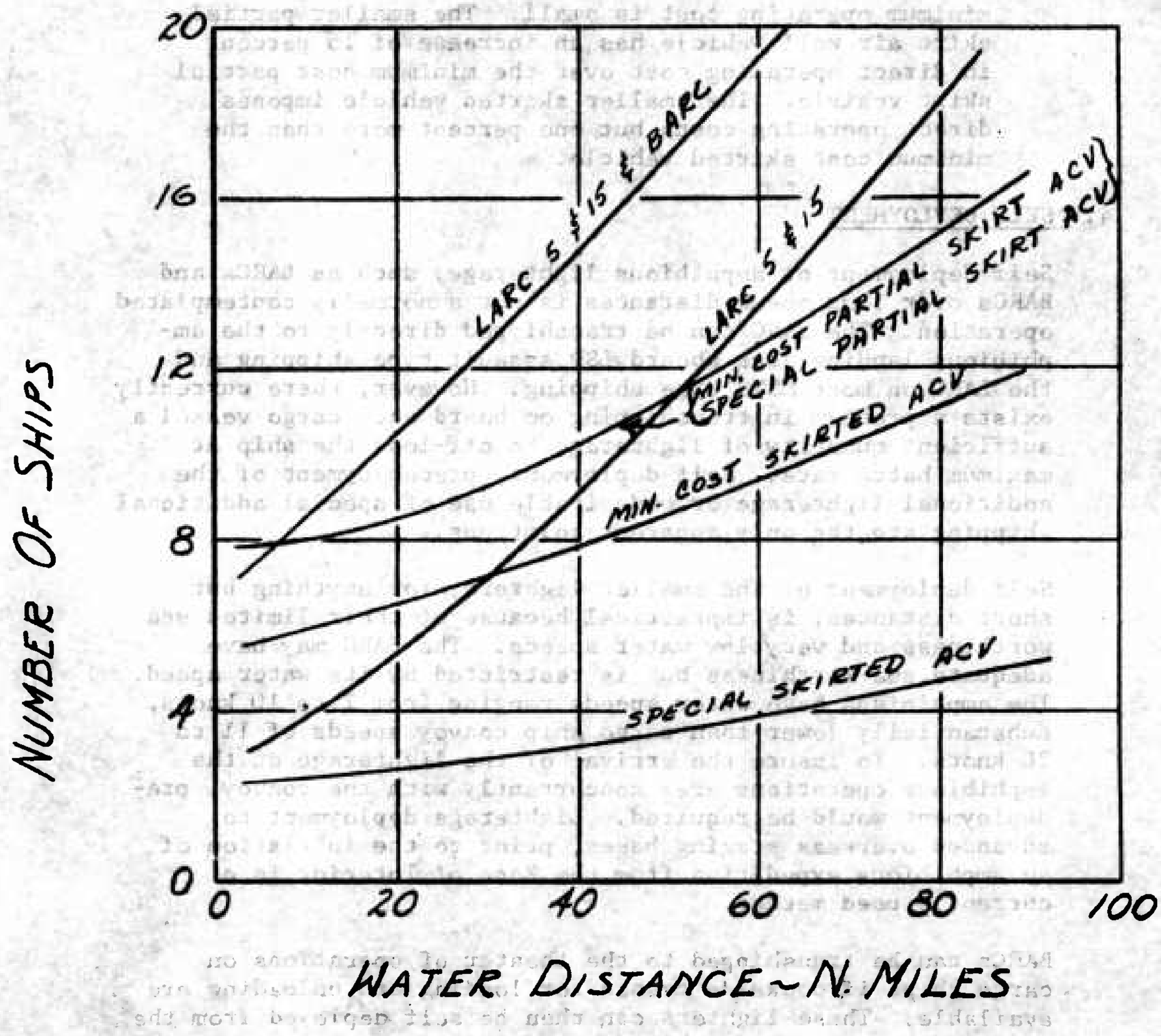


Figure III-24

As can be seen from Figures III-21 through III-24 the boom ratings and hatch rates chosen do not effect the ranking of the vehicles. The skirted ACV exhibits a potential for the least transhipment space requirement of all the lighterage studied. Its characteristic for carrying a larger payload than the air wall vehicles for a given planform area more than compensates for its lower speed when transhipment space is the criteria.

In general, it can be concluded that ACVs suitable for the broad spectrum of LOTS missions pose substantially less of a transhipment problem than current amphibians. The penalty in operating cost that is incurred when the ACV is sized for ease of transhipment rather than for minimum operating cost is small. The smaller partial skirt air wall vehicle has an increase of 15 percent in direct operating cost over the minimum cost partial skirt vehicle. The smaller skirted vehicle imposes direct operating costs but one percent more than the minimum cost skirted vehicle.

4. SELF DEPLOYMENT

Self deployment of amphibious lighterage, such as LARCs and BARCs over long ocean distances is not a normally contemplated operation. The BARC can be transhipped directly to the amphibious landing area aboard LSD assault type shipping and the LARC on most MSTS type shipping. However, there currently exists a problem in transhipping on board each cargo vessel a sufficient quantity of lighterage to off-load the ship at maximum hatch rate. Self deployment, predeployment of the additional lighterage or undesirable use of special additional shipping are the only apparent solutions.

Self deployment of the smaller lighters, for anything but short distances, is impractical because of their limited sea worthiness and very low water speeds. The BARC may have adequate sea worthiness but is restricted by its water speed. The amphibians have water speeds ranging from 7 to 10 knots, substantially lower than cargo ship convoy speeds of 11 to 20 knots. To insure the arrival of the lighterage at the amphibious operations area concurrently with the convoy, predeployment would be required. Lighterage deployment to advanced overseas staging bases, prior to the initiation of an amphibious expedition from the Zone of Interior is a currently used method.

BARCs can be transhipped to the theater of operations on cargo ships if dockside cranes for loading and unloading are available. These lighters can then be self deployed from the advanced base to the amphibious operations area.

Self deployment of the LARCs or BARCs from an overseas base to the amphibious operations area will be entirely dependent upon the distance involved and the sea conditions expected. It is not considered likely that LARC self deployment is an operation that could normally be relied upon. Assume the distance from the overseas base to the amphibious operations area to be 500 nautical miles. At a 7 knot water speed the trip would take three days. Vehicles of this type are designed for short cargo hauls and have no provisions for extra crew members, sleeping accommodations, eating facilities, comfort equipment, environmental protection (other than the basic control compartment), ocean survival equipment, long range navigational equipment, or long range fuel capacity. Substantial "deployment kit" provisions would be required by the slow speed wheeled amphibians for all but the shortest of trips.

Self deployment of an ACV overseas poses some of the same problems as to crew provisions, navigational equipment and fuel stowage as do the amphibians. However, due to the sizeable speed advantage of the ACV, most of these problems are less severe. The Los Angeles to Hawaii leg of a Pacific deployment is 2,200 miles. A 60 knot ACV would take 37 hours to make the trip. A 7 knot amphibian would require 13 days. Obviously, the provisioning requirements for the ACV would be substantially less due to greater space availability on ACVs and such a ferry operation does not appear impractical from crew comfort considerations.

Predeployment of ACVs to overseas staging bases followed by self deployment to the amphibious operations area seems well within practical consideration. A 500 to 1,000 mile deployment from the staging base to the landing site involves a ferry trip of 8 to 16 hours. The ACVs considered in this study have design gross weight ranges up to 1,600 miles. These ranges are based on utilizing the payload capacity for extra tankage and fuel. Their range capabilities together with the reasonably short ferry times may provide substantial flexibility and reaction capability for deployment throughout the overseas theater of operations.

A minimum cost partially skirted air wall vehicle provided with ferry tankage could travel 1,600 nautical miles at an operating height of 3.0 feet (6.0 foot wave clearance). As the vehicle proceeds toward the destination, consuming fuel, it has an increasing capability of rising to operating heights in excess of the 3.0 foot operating height. Figure III-25 shows the operating heights to which the vehicle could rise as a function of its distance from the destination. If the

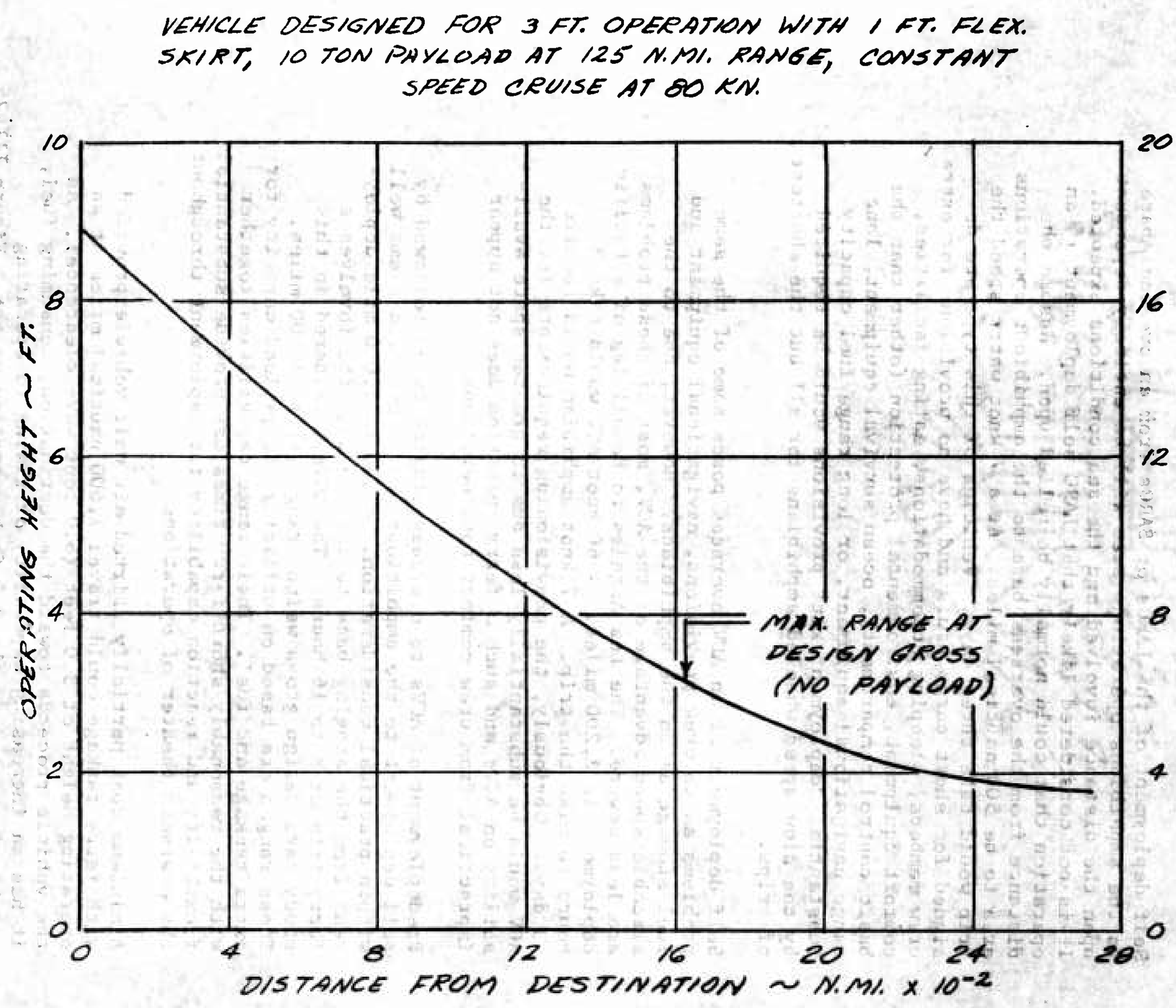


Figure III-25. Air Wall Air Cushion Vehicle Maximum Operating Height in Self Deployment Operations.

vehicle was required by sea conditions to operate for significant periods at these higher heights, its range would be reduced. However, the vehicle would have a range of approximately 1,000 nautical miles even if it was necessary to operate at the highest heights it is capable of throughout the trip.

Figure III-25 shows that such an air cushion vehicle embarking upon a self-deployment trip would have a substantially increasing wave clearance capability as it approaches its destination. At its destination it would have a capability of negotiating waves in excess of 16.0 feet. This operating height results in an equivalent h/d of approximately .17, which presents no vehicle stability problem (Reference 21).

It is estimated, therefore, that the 1,600 to 1,000 nautical mile ferry trips present no insurmountable technical problems, and successful accomplishment can be anticipated with a reasonably high probability. However, operator fatigue proglems, navigation problems and crew comfort considerations may well dictate against the long (34 hour) 2,700 nautical mile transoceanic voyage.

Self deployments of the air cushion vehicle over 1,500 nautical mile stages (19 hours and also 13 percent greater range than the longest leg of a transatlantic ferry) may be considered operationally possible and could be utilized to circumvent the problem of lighterage transhipment from advance bases to the area of operation.

Operational experience with the LOTS air cushion vehicle is required to fully determine the practicality of self-deployment operations.

(U) SECTION IV

MEASURES OF EFFECTIVENESS

A. QUALITATIVE FACTORS

The previous section has presented many of the factors affecting the LOTS mission which are unquantifiable. These factors are grouped herein and discussed to indicate the degree to which they may be considered as measures of the lighter's effectiveness.

1. FLEXIBILITY OF OPERATIONS

The item of military equipment that excels in every application and every environment is, indeed, a rarity. The characteristics leading to its excellence in one application often detract from its effectiveness in a second. In general, the best that can be expected from a given item of equipment is superior performance in its primary functions and a broad area of application at acceptable efficiencies in allied functions. The equipment that provides the military commander the greatest flexibility in operations at acceptable system costs is one to be sought. A full appreciation of the total capabilities of an equipment is essential to its proper and most effective use in military operations and is of equal importance to the military planner in developing service-wide requirements for its application. Promise of at least equal performance at substantial savings in system costs, or increased military capability at acceptable increase in system cost, are a measure of military worth.

Each of the following measures of effectiveness contribute to operational flexibility. An item of equipment, such as the air cushion vehicle, that provides satisfactory performance in most or all of these areas should prove to be of substantial military value.

2. PERFORMANCE IN NATURAL ENVIRONMENTS

The natural amphibious qualities of the air cushion vehicle, as previously indicated, provide military usefulness in adverse terrain environments which can seriously restrict some surface borne equipments. Quantification of all natural

terrain environments is not considered practicable. The military effectiveness gained by operation over the adverse terrain can only be determined for a specific situation by detail study.

A summary of the ACVs performance potential over the sea environment and over adverse terrain is, however, desirable to provide a qualitative appreciation for its possible effectiveness in military operations.

a. <u>Over Water Transit</u>

Within the clearance height limits of the ACV there will be no deterioration in lighter speed because of sea conditions. As sea conditions reach proportions where excessive wave impact is probable, prudent operation would dictate reduced operating speeds, particularly on cross wind or cross sea courses.

The operating heights of the ACV above the sea will significantly lessen water damage to cargo caused by driven spray, or as a result of taking water into the cargo compartment.

b. <u>Surf and Sea Approaches</u>

The ACV can negotiate shallow water, tidal flats, sand bars and reefs without diminishing speed. It is unaffected by ocean currents.

The ACV can negotiate surf within clearance heights without diminishing speed. Operating speed in the highest surf may be slowed to reduce the force of wave impact in a rapid transit through the surf line, or be regulated to the speed of advance of the waves as a means of avoiding the highest crests. As the ACV is continuously cushion borne in its transit of the surf line, there is no abrupt change from flotation to grounding in the beaching operation or in transition to wheeled travel over the beach. Broaching is not a consideration in ACV operations. Traversing the surf outbound will not affect the ACV when surf conditions are within its clearance height. Further, such passages will normally be made in the light load condition and operating clearance heights in excess of those attained on the inbound passage may be expected.

c. <u>Crossing the Beach</u>

The ACV will cross a beach without difficulty in that it is unaffected by the trafficability of the sand surface.

Smooth sand will permit proportionate reductions in operating height, reduce the volume rate of flow of cushion air and thereby serve to reduce the surface disturbance. Dunes may form an obstacle to movement because of their surface slopes or the limiting lateral clearance that may be encountered in negotiating a passage between them.

d. Cross Country Mobility

Amphibious lighterage should be considered in accordance with its cross country mobility. While it is generally unrealistic to consider transporting military vehicles overland, there are inland environments that many ground contact vehicles cannot negotiate, or in which they suffer such degraded performance that the feasibility of further movement is debatable. When such natural obstacles are encountered, or develop as the result of changing climatic conditions, the ability to surmount them with appreciable individual vehicle or total tonnage capacities may provide a significant military advantage.

The LOTS air cushion vehicle is intended for volume cargo transport. Consequently, it carries a large payload and, therefore, is a large size vehicle in comparison to smaller payload ground contact vehicles.

The ACV, like large ground contact vehicles, will have limited capability in negotiating forested terrain, except that it, unlike ground contact vehicles can fully utilize waterways or minimum prepared routes. Vehicle dimensional form imposes an absolute lateral clearance requirement which may be amplified in practice by lack of preciseness of air reaction controls. The vehicle will negotiate cultivated fields, swamps, marsh grasses and brushland with full performance within the limitations of its operational clearance height.

However, as indicated previously, high speed operation of the LOTS air cushion vehicle over typical vegetated rolling terrains can be obtained with minimal effort by provision of clearways.

The ACV can utilize rivers and inland waterways which present obstructions to land surface transport as some of the most favorable natural inland traffic routes. It is unaffected by water depth, currents or underwater surface conditions. It will be able to negotiate rapids in either direction and falls up to its operating clearance height. It may be constrained in its inland waterways

operations by clearance width and in speed by the frequency and radius of course changes. It will be able to negotiate marshland, sand bars and other natural obstacles to water borne lighterage without deteriorated performance.

e. <u>Soils</u>

Soils will have little effect upon the operation of the ACV. Dust may become a visibility hazard in the hover condition and between following vehicles. Current data would indicate that this problem could be reduced or eliminated by deflectors or suppressors. Low operating heights consistent with surface roughness will serve to reduce the amounts of dust raised, as well as cushion power requirements. Increasing moisture content of the soil will serve initially to reduce, and eventually to eliminate, the dust problem, but will have no deteriorating effect upon operations. Neither the depths or consistency of mud, snow or slush that would mire ground contact vehicles will slow or increase propulsive power expenditures of the ACV. This one significant and unique capability of the ACV potentially provides solution to one of nature's most frequent hinderances. to a military campaign.

Reduced traction associated with mud, ice and snow will neither affect speed nor safety of operation of the ACV. The ACV will be able to negotiate deep and drifted snow without interference. Thin ice and crusted snow should improve its operations by reducing the vehicle signature.

f. <u>Natural Obstacles</u>

The ACV, at low speeds, can negotiate all obstacles within its operational clearance height. Angles of Approach and Departure, as defined for wheeled or tracked vehicles, are dependent upon design concepts and are not readily definable. The dynamics and maneuverability of the individual design will determine the variation in safe obstacle clearance with increased operating speed.

g. <u>Gradability</u>

ACV design cannot economically provide the capability to climb slopes achieved by wheeled and tracked vehicles, when the latter are operated in highly favorable conditions of good traction on a dry, even surface. However, this maximum performance of ground contact vehicles in negotiating 50 percent to 60 percent grades is subject to rapid deterioration as surface roughness and surface penetration increase and traction decreases. The ACV is

not degraded by surface conditions, except as surface roughness approaches the degree and classification of obstacles.

Additionally, the ACV can utilize its inherent mobility to circumvent steep grades via routes which are possibly denied surface contact vehicles.

3. <u>RADIUS OF ACTION AND RESPONSE SENSITIVITY</u>

Lighterage speed is an easily measurable characteristic and the total costs of obtaining increased operational speed in a given design can be readily compiled. However, the total military advantages to be gained through the availability of increased operational speeds are not possible to assess in quantifiable terms, unless a specific military situation is considered.

As will be shown in the quantitative analysis, a major distinguishing characteristic of the ACV principle is that relatively high speed is attainable in the lighterage application at costs competitive with surface contact vehicles. This characteristic becomes even more favorable from the military point of view when it is recognized that ACV design speeds are operationally practicable throughout a wide range of environmental conditions that seriously reduce the safe operating speeds of other types of lighters or prevent entirely the inland operation of competing types of amphibians. Speed increases the responsiveness of lighterage to the changing military situation and acts to extend the distances over which it becomes economical to conduct lighterage operations. The combination of extended operating distances and timely response to operating requirements offer the following military advantages:

(1) Affords the responsible commander a greater latitude in choice of ship unloading sites and an added diversity in ship dispersal patterns.

(2) Affords a similar increase in flexibility in the dispersal of inland cargo transfer and unloading sites.

(3) Affords an opportunity to operate at extended distances over natural ACV routes, such as shallow water, marshland and other terrain that hinder or prevent the passage of either water borne or ground contact vehicles.

(4) Permits rapid concentration of lighterage from diverse locations for maximum rate unloading at a single site or to meet the demands of local variations in work loads.

(5) Provides rapid response to a lighter command and control system with reduction in the queuing problem and increased flexibility in adjustment to changes within localized operations.

(6) Makes selective discharge of priority LOTS cargo with intersite distribution by lighter an economically attainable objective.

(7) Permits self-deployment of lighterage (within range limitations) at speeds in excess of the rate of advance of fast amphibious shipping.

The attractiveness of these military capabilities are considered of sufficient importance to warrant analysis of lighterage operations throughout the range of reasonably attainable speeds and at extended operational distances. Accordingly, quantitative analysis of lighterage operations has been extended to disclose the practical economics of high speed ACV lighterage operations to distances of 75 nautical miles over water and 10 nautical miles inland.

4. <u>ABILITY TO SURMOUNT MILITARY OBSTACLES</u>

Primary military obstacles to water borne lighterage are mine fields, and implaced or natural underwater obstacles which can hole the craft. It is considered that the ACV lighterage, with its low cushion pressure, will be well within the bottom pressure variations engendered by such natural phenomena as tide changes and wave action. Its signature to pressure sensitive mines is, therefore, within the noise level of the mine's environments. Non-ferrous metal construction of the ACV will give it a very low signature to mines triggered by magnetic sensors, with further reduction attainable by use of degaussing equipment in the engine compartment. Additionally, low cushion pressures of the ACV amphibian give it relative immunity to land mine fields as compared to ground contact vehicles, while its operating height above the surface permits it to surmount all under water obstacles and those surface obstacles within its clearance height.

5. SECONDARY OPERATIONS

a. Ferry Operations

The ACV amphibious lighter has potential as a military ferry, with capability of negotiating landing approaches, shoal waters and obstacles that would hinder waterborne lighterage operations. Its speed permits rapid deployment along the shoreline or over inland waterways to the scene of operations. Additionally, its amphibious capability allows it to load and unload from defiladed positions ashore, rather than at the water's edge.

b. Tanker Operations

The ACV lighter has potential as an amphibious tanker, not only for the support of its own fuel requirements, but as an emergency back-up in case of casualty to the primary means of bulk fuel distribution. Capacity tankage provided for self-deployment should be designed for installation with employment of the lighter as an emergency tanker in view. Cargo space dimensions will normally be ample to permit the installation of tankage for either rated load or rated overload capacities of bulk fuel cargos. This ability to rapidly transport fuel in bulk quantities in emergency situations can prove to be of immeasurable value to the success of a military campaign.

6. IMPACT OF INTRODUCTION INTO SERVICE INVENTORY

Design of a military equipment must extend to considerations of the impact its introduction into the service inventory will have upon current military capabilities. While aiming at realizing the earliest and greatest possible military advantage from the new equipment's operational potential, its introduction must be accomplished with a minimum reduction in military capability during the transitional period. Within this approach, it is considered that ACV lighterage can be designed to require average operational and maintenance skills. It can be operated in conjunction with present types of lighterage under the same standing operating procedures. It is compatible with current complementary equipments and will operate to advantage with advanced equipments that may be introduced into the inventory. It can be introduced into an organizational structure compatible with standard Army combat support and service organizations.

B. QUANTIFIABLE FACTORS

The final measures of effectiveness of any item of military equipment are determined by its use in a real military environment. However, military capabilities of transport systems can primarily be defined in general terms of productivity and cost per unit productivity. When a new capability is developed, or an existing capability is extended, effectiveness becomes difficult to quantify in the absence of operational experience. However, improved concepts of operation and the costs involved can usually be quantified to a sufficient degree of accuracy to make meaningful comparisons with existing equipments and concepts.

The factors affecting the military capabilities and the system costs of air cushion vehicle lighterage, as utilized in LOTS operations are, therefore, quantified where practical in this report. This quantified data is compared with similar data on specific existing and competing forms of lighterage.

The study provides an analysis of a significant portion of the Army's LOTS operations and associated missions.

Air-Cushion Vehicles are analytically derived for providing minimum lighterage costs within their payload capacity. Additionally, the vehicles are required to operate in the most severe environments in which complimentary LOTS operational equipments permit conduct of operations.

It is not clear at this time that a requirement exists for replacement of the largest wheeled amphibians (BARC) which are capable of transporting the largest weight military equipments. Therefore, no attempt has been made to determine the ACV lighterage family or mix of ACV and other lighterage which provides total capability at minimum system cost. Rather, the derived air cushion vehicles are required to carry the equipments predominate to resupply operations - - pallets, Conex containers, bulk and filler cargoes and major proportion of wheeled and tracked vehicles - - which weigh under 10 tons. Additionally, the ACVs are required to have payload capacities to 25 tons when operating in favorable environment which makes them capable of carrying all but the largest weight items of Army equipments (i.e., tanks, tank retrievers and self-propelled guns).

The primary measure of effectiveness that has been developed and compared in this study is the total system cost to provide the maximum system productivity permitted by the constraining item in the system - the ship's hatch rate.

In the development of this parameter several side factors evolve which are meaningful on their own:

(1) Impact on the budget (cost to procure the required LOTS capability).

(2) Manpower required to maintain the required level of productivity.

(3) Fuel consumed in maintaining the required level of productivity.

(4) Number of lighters required to maintain the required level of productivity.

(5) Transhipment costs required to deliver sufficient lighterage to provide the required level of productivity.

(6) Engineer road construction costs and their influence on operating costs.

(7) Shipping space required for transhipment of lighterage.

(8) Lighter response time as a function of operating cost.

(9) Cargo space limitations in respect to useful payload capacity.

The groundwork for some of the above quantifiable measures of effectiveness has been developed in Section III. The costing factors are developed and compared in the following sections.

(U) SECTION V

AIR CUSHION VEHICLE COST AND CHARACTERISTICS ANALYSIS

A. GENERAL

It is necessary to develop the costs and characteristics of air cushion vehicles which are representative of practical operational vehicles in the 1965 to 1970 time period to permit:

(1) Comparison of their capabilities and costs with competing vehicles.

(2) Delineation of the vehicle characteristics which provide increased military usefulness.

(3) Determination of their compatibility during LOTS operations with other equipments of the logistic supply system.

(4) Disclosure of the vehicle characteristics which could possibly degrade their operational usefulness; and to permit estimation of possible means for avoiding those undesirable characteristics or overcoming such degradations.

The purpose of air cushion vehicle studies reported in this section is to provide representative data on air cushion vehicle costs and characteristics. No attempt was made to define the characteristics of a single vehicle design in detail. Rather, the investigations covered many possible vehicles analytically to determine those which best satisfy the requirements of LOTS operations.

Results of these studies should, therefore, be regarded as the contractor's best estimates of vehicle characteristics that can be achieved in the 1965 to 1970 time period with good engineering and adequate research and development.

Additionally, it should be recognized that solutions to several air cushion vehicle technical problems have not yet been demonstrated. For example, control and stability characteristics adequate for providing operationally useful vehicle center of gravity ranges, dynamic response characteristics and vehicle control response are still not demonstrated. While current knowledge indicates successful solutions are obtainable to the foregoing problem areas, the vehicle configuration factors and operational limits permitting such solution are not well defined.

B. TYPES OF AIR-CUSHION VEHICLES CONSIDERED

Vehicle concepts incorporating a peripheral jet and base compartmentation for achieving adequate stability have been given the most attention experimentally and analytically by investigators, both in the U.S. and abroad. Consequently, the greater technical knowledge of the concept leads to its logical selection as a major candidate for the LOTS amphibious vehicle. This is particularly true in view of the 1965 to 1970 operational time period this study is concerned with. There are, however, several other basic air cushion vehicle concepts which have potential merit in the LOTS application.

Amongst those considered and rejected for this study are the simple ram-wing types, the recirculation-diffuser types, simple plenum chamber types and simple hydroskimmer types.

The simple ram-wing type is rejected on the basis of its inability to economically perform the inland portion of the mission, which requires efficient operation in restricted quarters during both hovering and extended low speed operation. The simple plenum chamber type is rejected due to its inferior performance in comparison to others. The limited technology on recirculation-diffuser types makes questionable their consideration for the 1965 to 1970 operational time period. Simple hydroskimmer types, incorporating skegs immersed in the water, are rejected since they are limited to overwater operation.

A plenum chamber vehicle type, incorporating a flexible peripheral skirt extending to the ground, was also investigated. This vehicle concept offers the potential of permitting significant reductions in power required for lift. Further, this fully skirted concept offers reductions in vehicle size in comparison to pure peripheral jet types.

Hydroskimmer type vehicles incorporating a jet exiting from the skegs in addition to transverse jets at bow and stern, also potentially require less power for lift than pure peripheral jet types, offer possible size reduction, and exhibit some overland capabilities. The amphibious type of hydroskimmer vehicle was, therefore, included in the analysis.

Additionally, vehicles possessing a peripheral jet and peripheral flexible skirting, which does not extend to the ground, were considered. Such vehicles are intermediate to the simple peripheral jet and the fully skirted plenum chamber types. The lifting flow exit conditions and power requirements of these vehicles are dictated by the distance between ground and skirt lower edge, jet thickness to height ratio and the degree of skirt porosity.

Initial investigation of vehicle characteristics was conducted assuming use of shaft turbine powerplants driving appropriate high mass flow, low velocity air flow actuators. The effect of utilizing reciprocating power plants on the vehicle characteristics was also determined for a limited number of design points. The vehicles powered with reciprocating engines were found to be larger, require greater amounts of power and cost more to operate than turbine powered vehicles when designed to the same mission capabilities. However, even though the reciprocating powered vehicles are larger, their fuel consumption was found to run approximately 70% of that for the turbine powered vehicles.

C. VEHICLE SELECTION AND DESIGN CRITERIA

Military objectives for the LOTS operations and the factors affecting the operations have been discussed in previous sections. These provide the basis for vehicle selection and design criteria. The most significant ones are briefly summarized here for completeness.

(1) The daily resupply of Army units in the field (1440 short tons of dry cargo per Army Division Slice) from a ship at

sea to a mobile inland cargo transfer point. The off-shore distance is variable from approximately 2 nautical miles to 75 nautical miles. The inland distance is variable from first gaining the dry beach to approximately 10 nautical miles.

(2) Capability to operate at rated performance in those environmental conditions in which other equipments employed in LOTS operations do not impose reductions in system performance. For example, the air cushion vehicle must be capable of rated speed and payload in seas characterized by 3.5 foot significant wave heights. Such seas are considered to signify the onset of reduction in ships' hatch rate.

(3) Due to the continuous nature of resupply operations, it is necessary to determine the vehicle which provides the maximum system operational economy.

(4) The lighterage vehicle shall be transportable to the theater of operation aboard conventional MSTS and commercial cargo ships. A desired goal is to tranship a sufficient number of lighters aboard a single vessel to handle the discharge of that ship's cargo at its nominal hatch rate.

(5) The vehicle must be capable of operating to the inland transfer point over diverse and unconsolidated soils (e.g. mud, snow, marsh, etc.) with a minimum of obstruction removal and/or route preparation.

(6) The vehicle shall be capable of receiving and carrying the maximum possible items of equipment within its payload capacity. Additional payload capacity for favorable environment off-design operation is desirable.

The fundamental objectives stated above translate into the following vehicle design and selection criteria.

(1) Maximum economy for a given level of productivity.

(2) Size consistent with transport aboard conventional MSTS and commercial cargo vessels (Maximum vehicle dimensions of 35 feet width by 70 feet length).

(3) Operating height at rated payload consistent with cross-country mobility and seas characterized by 3.5 foot significant wave heights.

(4) Maximum possible cargo compartment size. Minimum cargo compartment size to be consistent with resupply cargo dimensions at rated payload.

D. METHOD OF ANALYSIS

Parameter variations were utilized as the means for exposing the desired vehicle characteristics. The parameters to be varied and the range of values and constraints imposed on certain of the vehicle characteristics were chosen on the basis of the Army's objectives for LOTS operations and the factors affecting such operations.

1. PROCEDURE

Vehicle characteristics for each type of air cushion concept were generated to satisfy each combination of payload and performance parameter value assumed. This was accomplished by mathematical relationship of the vehicle's technical characteristics to determine the size of its major components (e.g. propulsion system, structure, etc.). Assumed values of cost were applied to each of the resulting vehicle components and a total initial cost was obtained. The vehicle's operating cost was derived from these values by amortizing the initial cost and adding the costs of maintenance, fuel, manpower and attrition. The vehicle possessing the minimum hourly operating cost and satisfying the parametrically assigned performance requirements was determined at each combination of payload-performance parameters. The total daily costs for lighterage were then computed for each of the minimum operating cost vehicles. The vehicle possessing the minimum daily costs at each design radius of action and operating height was then selected for further comparison.

2. OPERATIONAL PARAMETERS

As previously indicated in Section III-D, single valued criteria for operating height and design radius of action are not obvious. The criterion for operating height is dependent upon the unquantifiable natural environment

encountered operationally and to a lesser extent on design philosophy. The design range of the vehicle is, as previously indicated, dependent upon LOTS operational concepts and doctrines in the 1965 to 1970 time period. Height of operation and mission radius were, therefore, maintained as variables throughout the major portion of air cushion vehicle characteristics analysis.

a. Operating Height

Operating heights varying from a low of .75 feet to a high of 5.5 feet were explored. The maximum over-ground operating heights measured to the hard structure base of all vehicles was selected at 5.5 feet to insure the investigations covered a representative range of possible overland travel obstruction clearance requirements. The highest operating height is estimated to permit hard structure clearance of wave heights to 11 feet for the air wall type vehicles. The fully skirted vehicle, with ground operating heights of 5.5 feet, is estimated to be capable of clearing wave heights to 8.25 feet with its hard structure. The base of hydroskimmer type vehicles studied are estimated to clear wave heights to 7.2 feet without flexible skirting on the bow and stern. Flexible bow and stern skirts are possible and could permit the hydroskimmer vehicles to clear higher wave heights. The differences in maximum wave height clearance capability of the three different vehicle types arises from the manner each type is estimated to behave over a sinusoidal sea, aligned perpendicularly to the vehicle's path.

b. Range

The vehicle's design range was determined by summation of the over land and over water mission radii, plus an allowance for queuing and maneuvering along shipside, at the surf and at the inland transfer point. The queuing allowance is included in the allocated maneuver times.

The equation utilized to determine the design

range is:

$$R_{eq} = 2\left(\frac{D_1}{V_1} + \frac{D_2}{V_2}\right) + (M_1 + M_2 + M_3)\ V_1$$

where

D_1 = the distance from ship to shoreline $\sim$ n. miles.

D_2 = the distance from shoreline to inland transfer point $\sim$ n. miles.

V_1 = cruise speed over water $\sim$ knots.

V_2 = cruise speed over land $\sim$ knots.

M_1 = time to decelerate (or accelerate), maneuver and tie-up (or cast-off) at shipside, including queuing $\sim$ 11 minutes

M_2 = time to negotiate surf at reduced speeds $\sim$ 2 minutes

M_3 = time to refuel, maneuver, clear inland loading activities and accelerate to cruise speed $\sim$ 3 minutes

Combinations of assumed values for inland distances to ten nautical miles and water distances to 75 nautical miles were employed.

c. Fuel

The fuel requirement of each vehicle was determined from the parametrically assigned range requirement, cruising speed and cruising power at gross weight. A modified form of the Breguet range equation was used to express the fuel requirement as a fraction of vehicle gross weight. The equation used is:

$$\frac{W_F}{W_G} = 1 - \frac{1}{e^{\left[\frac{(R)\,(SHP_{cr})\,(SFC)}{(V)\,(W_G)}\right]}}$$

Where

$\frac{W_F}{W_G}$ is the fuel weight fraction of gross vehicle weight.

R	is the vehicle equivalent range $\sim$ n. miles
SHP_{cr}	is the cruise shaft horsepower
SFC	is the specific fuel consumption in pounds of fuel per shaft horse-power per hour.
V	is the vehicle speed in knots
W_G	is the vehicle gross weight

d. Speed

The desirable speed of operation for the vehicles is dependent upon the vehicle's technical characteristics and the operational requirements. At large radii of operation, high speed is important in reducing the number of vehicles required and, therefore, costs. At short distances the time required for loading, unloading and maneuvering, over-shadows any influence that vehicle operating speed can exert on the number of vehicles required. The effects of operating speed on number of vehicles required are shown on Figure III-1. The vehicle speed resulting in minimal daily lighterage cost was determined by varying the inland speeds from 0 to 35 knots and the overwater speeds from 0 to 80 knots.

e. Payload

The effects of payload on lighterage cost are tightly intermeshed with other facets of the operation. As indicated earlier, the ship's cargo unloading rates markedly influence the vehicle's cycle time and productivity. Consequently, the vehicle payload resulting in most economical lighterage operation is largely dependent upon the cargo handling rates, as well as vehicle operating speed and mission radii.

Vehicle payloads ranging from 5 short tons to 25 short tons were investigated to determine the vehicle payload resulting in minimum lighterage costs for delivery of specified daily tonnages.

f. Hatch Rate

Hatch rates are currently quoted as averaging

7.2 short tons per hour, but are demonstrated to average 15 short tons per hour, using currently operational equipments that are coming into more widespread use. The 15 short tons per hour hatch rate is considered representative of the 1965 to 1970 time frame and is the nominal value assumed.

Initial investigations were, therefore, accomplished with the assumptions of a 15 tons per hour hatch rate, in combination with a 20 ton per hour unloading rate. Additional investigations assuming hatch rates of 7.5 tons per hour and 30 tons per hour, with accompanying unloading rates of 10 tons per hour and 40 tons per hour, respectively, were accomplished to expose hatch rate effects on desirable vehicle payload and minimum lighterage costs. In all cases, the costs per ton delivered were computed assuming the hatch rate to be continuous.

3. COMPUTATIONS

The method of analysis was translated into an IBM 709 computer program. The mechanization of computational procedures provided by this tool permitted rapid investigation of the sensitivity of vehicle characteristics and lighterage costs to the many operational, cost and technical parameters which serve to define the air cushion vehicle.

Investigation of effects of variations to the following air cushion vehicle parameters are possible with the computer program.

(1) Equivalent Range

- a. Overland distance
- b. Overwater distance
- c. Overland speed
- d. Overwater speed
- e. Delay time

(2) Payload

(3) Operating Height

(4) Size Constraint

(5) Ratio of Vehicle Width to Length

(6) Planform Loading

(7) Maneuver Capability

(8) External Drag

(9) Costs

a. Structure
b. Propulsion System
c. Manpower
d. Amortization
e. Attrition
f. Maintenance
g. Fuel

(10) Weights

a. Propulsion System
b. Structures
c. Fixed Equipment

(11) Efficiencies

a. Duct
b. Lift Fans
c. Propulsion
d. Ram Recovery at Fan

(12) Peripheral Jet Variables

a. Jet thickness to height - te/h
b. Jet inclination angle - θ
c. Ambient pressure distribution - p_o
d. Jet thrust $\sim$ Beta vanes
e. Intraventing Power

(13) Skirted Vehicle Variables

a. Skirt discharge coefficient
b. Variables listed for peripheral jet

(14) Hydroskimmer

a. Skeg heights
b. Ratio of base to skeg heights
c. Variables listed for peripheral jets and skirts.

The results of the analysis are presented in later Sections of this report. These results are based on assumptions and estimates reflecting air cushion vehicle technology, costing factors and operational considerations. The air cushion vehicle technology and costing estimates and assumptions follow.

E. ASSUMPTIONS AND ESTIMATES EMPLOYED IN VEHICLE ANALYSIS

1. AIR WALL VEHICLE FLOW AND CONFIGURATION FACTORS

The analysis of flow exiting from air wall (peripheral jet) vehicles was accomplished with use of the exponential theory propounded by Stanton-Jones (Reference 22). Correlation of the Aeronutronic experimental data with the exponential theory is given in Reference 23, shows the exponential theory provides adequate accuracy for peripheral jet exit flow analysis.

The jet exit flow conditions at forward speeds were computed in the manner described in Reference 24 with the following assumptions of air pressure distribution around the vehicle:

(1) Ambient air pressure along the vehicle sides
(2) Ambient air pressure plus free air stream dynamic pressure acting at the front of the vehicle
(3) Ambient air pressure minus one-half free air stream dynamic pressure acting at the rear of the vehicle

Beta vanes are assumed to be located in all longitudinally-oriented jet exits. The beta vanes are assumed to provide the air exiting from the longitudinal jets with a velocity component equal to that of the free air stream. Therefore, no net momentum drag arises from air exiting the longitudinally oriented jets. Momentum drag is experienced from flow exiting the aft transverse jet. The thrust, or momentum drag, of the front jet is computed.

The transverse jet exits are assumed to have variable thickness. A constant base pressure is maintained with changes in vehicle speeds by adjusting the thickness of the transverse jets such that the momentum of flow exiting from these jets is just adequate to sustain the pressure differential between the external and base pressures. Fan total pressure (P_t) is determined by the side jet conditions.

Intraventing jets that divide the base both laterally and longtudinally were assumed. These intraventing jets are provided to obtain adequate vehicle stability. It is assumed, based on Reference 21, that they cause a ten percent increase in power for lift and overcoming momentum drag.

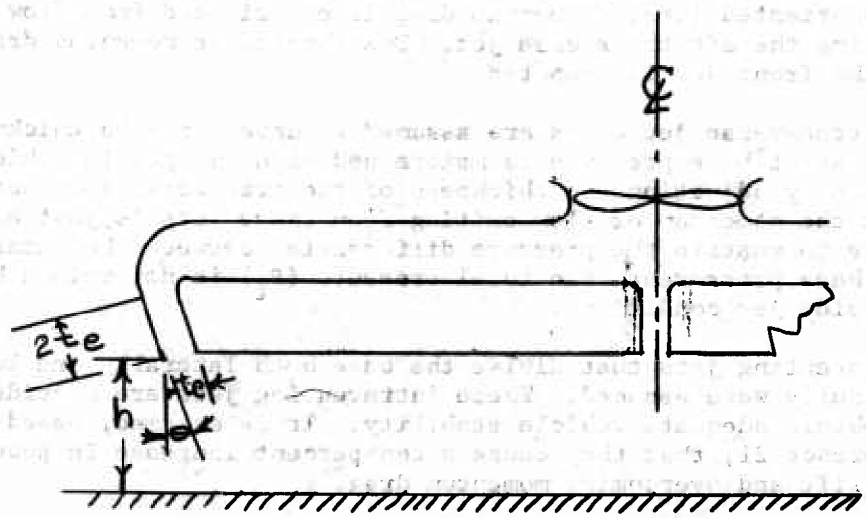
The side jet's thickness to height ratio (te/h) was initially varied to determine the thickness to height ratio resulting

in the minimum cost vehicle at one specific combination of design payload and range. As reported later in Section V-E, it was determined that a te/h value of .35 resulted in the minimum cost vehicle at most operating height and speed combinations. Further investigations of air wall air-cushion vehicles were, therefore, all based on an assumed side jet te/h value of 0.35.

The angle of the peripheral jet exit flow is assumed to be inclined 15 degrees from the vertical toward the center of the vehicle's base. A straight run of ducting aligned perpendicular to the jet exit plane with a length equal to twice the jet exit thickness is also assumed to insure that the peripheral jet leaves at the specified angle.

The 15 degree jet angle was selected as a compromise between vehicle size and performance considerations. Greater jet inclination angles are estimated to cause undesirable increases in overall vehicle width and weight. Lower jet angles reduce vehicle performance unnecessarily.

The accompanying sketch A schematically depicts the assumed jet exit geometry. The vehicle's lifting base geometry is assumed rectangular, having width equal to one-half the length.



SKETCH A

2. SKIRTED VEHICLE FLOW AND CONFIGURATION FACTORS

The lift forces and lifting air flow characteristics of the skirted air-cushion vehicle are typified by the plenum chamber concept. The effective flow exit area of the simple plenum chamber vehicle (height of vehicle multiplied by peripheral length) is reduced to approximately one-sixth of its initial value with incorporation of the flexible skirt elements. The equation expressing the flow exit area (A_{exit}) is

$$A_{exit} = c_d h l$$

Where c_d - is the discharge coefficient (assumed .6 for a simple plenum and .1 for fully skirted vehicle (Reference 47))

h - is the distance from vehicle hard structure to the ground

l - is the vehicle peripheral length

The base pressure of the fully skirted vehicle is assumed equal to 79 percent of supply air total pressure after it has entered the plenum chamber. A nominal 1 percent allowance between plenum total pressure and base pressure is included to account for the fact that complete stagnation of air in the plenum chamber is unlikely.

The flow velocity through the flexible skirts is computed on the basis of pressure differential between plenum chamber total pressure and pressure existing around the vehicle's periphery.

$$V_{exit} = \sqrt{\frac{2(p_t - p_o)}{\rho}}$$

Where V_{exit} = exit flow velocity

p_t = total pressure in plenum chamber

p_o = pressure at external surface of skirt

ρ = air density

The skirt external surface pressures are assumed to be the same as those for the air wall vehicle.

Momentum drag of the skirted vehicle is also computed similarly to that for the air wall vehicle with one notable exception.

Beta vanes are not utilized to eliminate momentum drag from the longitudinally aligned flow exit planes. Momentum drag is, therefore, experienced from flow exiting the vehicle through all of the skirts. Momentum drag of flow exiting the forward and aft skirts is computed on the basis of velocity differential between exit flow conditions and free stream conditions.

$$D_M = \rho A_{ex} V_{ex} (V_o - V_{ex})$$

Where D_M = momentum drag in pounds from flow out of a particular portion of the vehicle's skirt (e.g. side, front, aft)

ρ = density of air (.002378 $\frac{\text{slugs}}{\text{ft}^3}$)

A_{ex} = equivalent exit flow area of a particular portion of the vehicle (ft^2)

V_o = free stream velocity (ft/sec)

V_{ex} = velocity of exit flow in the axis of the free stream vector

The skirted vehicle's lifting base geometry is assumed to be rectangular, having width equal to one-half the length.

Lateral and longitudinal base compartmentation with flexible skirting to obtain adequate vehicle stability are conceptually incorporated. Current technology indicates that both the lift fans and skirt reactions with the surface will add to the skirted vehicle's stability. Experimental tests are required, however, to fully determine the skirted vehicle's stability characteristics.

Additionally, it is assumed that a given vehicle has the ability to extend or retract the flexible skirting parallel to the vehicle sides. The skirting employed for base compartmentation can also be adjusted in height. The adjustable skirt height feature is included to permit a specific vehicle to accommodate off-design environmental conditions.

3. PARTIALLY SKIRTED VEHICLE FLOW AND CONFIGURATION FACTORS

All vehicles considered conceptually incorporate peripheral jets.

The partially skirted vehicle flow characteristics are dependent upon assumed skirting geometry.

Vehicles with non-porous flexible skirts extending up to two-thirds the distance to the ground have been shown experimentally (Reference 21) to exhibit essentially the same flow, lift and power requirement characteristics as a vehicle whose base lies in the plane defined by the lower edge of the skirts.

The geometric and flow assumptions employed for the simple peripheral jet vehicles were, therefore, applied to the partially skirted vehicles.

The partially skirted vehicles considered in the analysis were assumed to use a non-porous flexible skirt.

While not specifically considered vehicles with partial skirting of porous design relate simply to partially skirted vehicles employing non-porous skirts. The relationship is established by the degree of skirt porosity, the percentage of skirt height to ground clearance height and momentum of the peripheral jet. The limiting case of a vehicle employing a porous skirt extending to the ground is analagous to a very thick jet vehicle operating at a reduced height such that the lifting air exit flow volume is equivalent to that permitted by the porosity of the skirt.

For example, a vehicle incorporating a peripheral jet with te/h of 2.3 has a base incremental pressure to jet total pressure ratio $\frac{pb}{pt_j}$ equal to .99 and behaves as a plenum chamber vehicle with a discharge coefficient of 0.9. A fully skirted vehicle with a porous skirt relates to such a vehicle in the following manner.

From the Stanton-Jones exponential theory for zero jet inclination angle; annualar jet vehicles with a te/h of 2.3 provides:

Base pressure coefficient (C_b)

$$C_b = .99 = \frac{\Delta pb}{pt_j}$$ which is equal to that attainable with a plenum chamber vehicle

$$c_d = C_v \frac{te}{h} = .9$$

Where c_d = discharge coefficient

C_v = discharge flow velocity coefficient

$= V_{exit} \Big/ \sqrt{\frac{2pt_j}{\rho}}$

The flow volume (Q) is given by

$$Q = c_d\, h\, 1 \sqrt{\frac{2pt_j}{\rho}}$$

$$= .9\, h\, 1 \sqrt{\frac{2pt_j}{\rho}}$$ for annulár jet vehicle with te/h = 2.3

$$= .1\, h\, 1 \sqrt{\frac{2pt_j}{\rho}}$$ for skirted vehicle with discharge coefficient of .1

The power required (P) is given by

$$P = pt_j\, Q = c_d\, hl \sqrt{\frac{2}{\rho}} \left(pt_j\right)^{3/2}$$

The lift (L) is given by

$$L = C_b\; pt_j$$

The lift to power ratio is, therefore

$$\frac{L}{P} = \frac{C_b\; pt_j}{c_d\, \frac{hl}{S} \sqrt{\frac{2}{\rho}} \left(pt_j\right)^{3/2}}$$

Vehicles possessing the same C_b, pt_j, operating height, base area and peripheral length can, therefore, be equated on the basis of equivalent operating height by the ratio of their discharge coefficients as follows:

$$h_{eq_2} = \frac{c_{d_1}}{c_{d_2}} \quad h_1$$

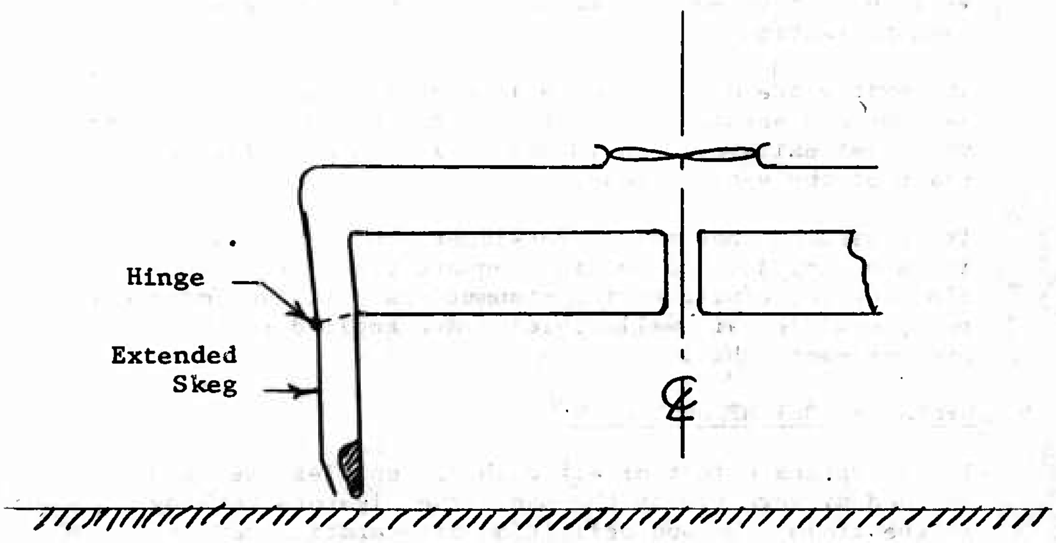
Caution must be exercised to insure that the value of C_b is the same for the compared vehicles when using this procedure.

Similarly, a vehicle incorporating a partial flexible skirt with some porosity behaves as a peripheral jet with non-porous skirting whose exit height lies above the lower edge of the skirt a fractional amount depending on the degree of porosity.

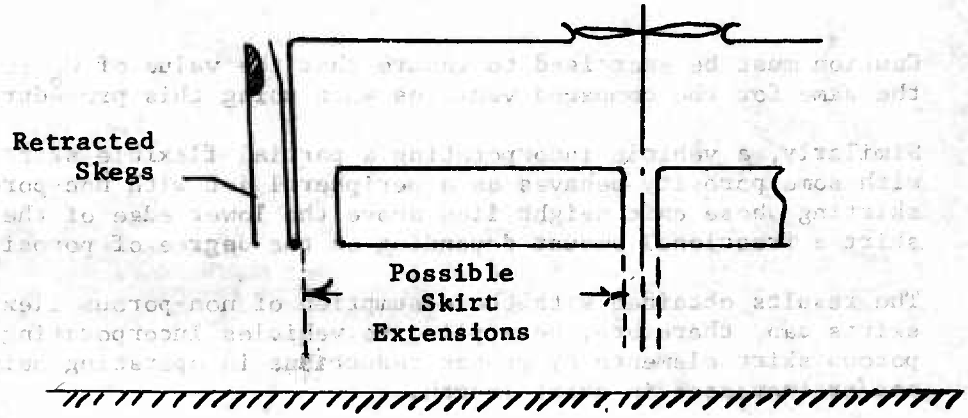
The results obtained with the assumption of non-porous flexible skirts can, therefore, be applied to vehicles incorporating porous skirt elements by proper reductions in operating height and/or increases in skirt length.

4. HYDROSKIMMER TYPE VEHICLE FLOW AND CONFIGURATION ASSUMPTIONS

The amphibious hydroskimmer vehicles considered in the study are capable of skeg retraction. Conceptionally the skegs fold flush to the vehicle's sides or base exposing peripheral longitudinal jet exits that lie in the same plane as the transverse jet exits. This feature permits the vehicle to operate as an air wall or partially skirted vehicle for overland travel and as a hydroskimmer for overwater operation. Sketches B and C schematically depict a head-on cross-section of a hydroskimmer vehicle employing retractable skegs.



SKETCH B



SKETCH C

The retractable skeg hydroskimmer vehicles were studied to determine if the minimum cost hydroskimmer vehicle configuration was superior to the other types considered. Both the overwater wave height clearance and, with skegs retracted, the overland obstruction clearance requirements should be achieved. However, it is not certain at this time that skeg retraction can be successfully accomplished and meet the design objectives. Retractable skeg hydroskimmer vehicles employing peripheral jets exiting from the lower edge of the extended skegs were also investigated, since it may be desirable to permit the vehicle to move some distance on to the beach prior to skeg retraction.

The exit plane of transverse jets on a particular hydroskimmer are assumed to be at the same height. The transverse jet exits are considered to lie in or below the plane of the vehicle base.

It is assumed that the hydroskimmer vehicles incorporate intraventing jets to obtain adequate stability. The jet flow and jet configuration assumptions utilized for the peripheral jet air wall vehicles are applied to the hydroskimmer vehicles.

5. OPERATING HEIGHT OVERWATER

The operating height of air cushion vehicles has been defined differently by the many investigators working in the field. No one definition of operating height

appears satisfactory to all concerned. It is suggested, however, that the operating height definition of interest is that which connotes the operating capability of the vehicle to successfully negotiate obstacles. The definition of operating height utilized in this report is, therefore, that which tells of the vehicle's ability to clear an obstruction with its hard structure when operating over a smooth hard surface.

The operating height of air cushion vehicles over water is dependent upon the vehicle type, planform loading, speed and the condition of the water.

The change from ground to water operating height of air cushion vehicles over smooth water is dependent upon their planform loading only. Hovering operation over smooth water causes the water beneath the vehicle to depress an amount proportional to the planform loading. The resulting height of the vehicle's hard structure to the free water surface is

$$h_{w(hover)} = h_g - \frac{W/S}{64}$$

where $h_{w(hover)}$ is the height of hard structure from the free water surface

h_g is the operating height over a smooth hard surface

W/S is the vehicle's weight divided by the base lifting area

At high forward speeds the depression of the smooth water surface caused by an air cushion vehicle is analagous to that occuring with an equivalent planing hull craft. The water depression slopes downward from the front of the vehicle to the rear and progressively diminishes with increasing forward speed. At speeds where the relative dynamic pressure of the water is high in comparison to the vehicle's planform loading, negligible water depressions result.

It is estimated by the method presented in Reference 27, for example, that a hypothetical 20 foot wide vehicle having a planform loading of 32 pounds per square foot would cause a water depression of .17 feet at its center when traveling at 40 knots.

Throughout this study it has been assumed that the water depression at cruising speeds is of negligible magnitude.

Air cushion vehicle operating height over wavy water is a complex function of many factors. Quantification of all natural phenomena bearing on the precise estimation of wavy water operating height is not within the scope of this study, nor is it considered practical. As previously indicated and reported in Section III D of this report, the wavy sea is composed of randomly distributed waves. The probability of encountering waves that will impact the hard structure of the vehicle is dependent upon the vehicle dynamics, operator judgement, and alignment of vehicle path to wave crest line in addition to vehicle operating height.

The following assumptions were employed in performing rudimentary estimates of wavy water operating heights of the various type air cushion vehicles.

(1) The waves are assumed to be constant amplitude and wave length, sinusoidal shapes which displace equally from the mean sea level.

(2) Wave length to height ratios of approximately twenty are assumed.

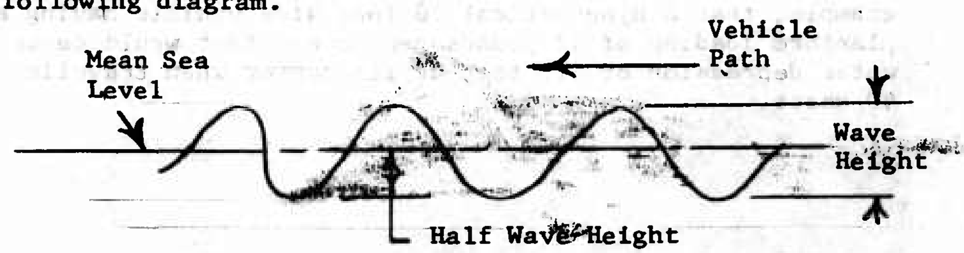
(3) Variations in wave length to height ratio result in negligible operating height changes due to time averaging.

(4) Wave encounter frequencies causing undesirable dynamic response are avoided.

(5) Low frequencies of wave encounter, permitting the vehicle to follow the wave contours, are treated as smooth water operation.

(6) The vehicle path is assumed to be aligned perpendicularly to the wave crest line.

The foregoing assumptions are schematically shown on the following diagram.



The study considers vehicles capable of withstanding wave impact. Vehicles not capable of withstanding wave impact are, as stated in Section III D, of questionable value.

As previously discussed in Section III D, operator opinion and vehicle dynamics effects on establishing operationally acceptable vehicle operating height and speed for all vehicles considered is beyond the scope of this study.

An allowance for the vehicle dynamics and operator opinion effects on required operating height was obtained by requiring the vehicles to impact not more than 1 in 100 waves during operation over wavy water. As shown on Figure III 10 of this report, seas characterized by 3.5 foot significant wave heights have average wave heights of 2.2 feet and no more than 1 in 100 waves exceed 5.5 feet. Hence, vehicles designed for full operational capability in seas characterized by 3.5 foot significant waves must be capable of clearing the crests of 5.5 foot waves with their hard structure.

a. Air Wall Vehicles

The wavy water operating height of the air wall type air cushion vehicle is assumed equal to its ground operating height when measured from the mean sea level. This assumption is justified by trials of the British hovercraft (SRN-1) and additional analysis reported in References 16 and 28. The trials and analyses have shown the air wall vehicle capable of operating clear of wave crests in sinusoidal seas having wave heights twice the vehicle's operating height over ground. The required operating height of air wall vehicles in seas with 3.5 foot significant waves is, therefore, 2.75 feet.

b. Fully Skirted Vehicles

The following assumptions were employed in performing rudimentary estimates of the operating height of fully skirted air cushion vehicles over wavy seas. (It should be recognized that existing technology on flexible skirt design does not permit accurate estimation of skirt behavior in contact with randomly distributed waves.)

(1) The lifting air flow volume, pressure and power remain constant with passage of the flexible skirt over and through the waves.

(2) The flow volume passing between the lower edge of the vehicle's skirt and the wave trough contour is equal to that blocked by the adjacent wave crest contour on a time average basis. This means that the effective skirt area covered by a wave crest is equal to the effective flow area opened by the wave trough. (Expressed mathematically, $C_{d_1} A_{blocked} = C_{d_2} A_{open}$)

Utilizing the foregoing assumptions, it was estimated that 40 to 70 foot long vehicles having length to width ratios of two should operate with the lower edge of the skirt approximately one-third the wave height above the wave trough. It was assumed that the skirted vehicles would not change operating height in response to randomly interspersed waves which are smaller or larger than the average wave height. The following expression was obtained to determine the hard structure operating height necessary to permit a probability of wave impact not exceeding 1 in 100.

$$h_{req} = \frac{h_{av}}{6} + \frac{h_{100}}{2}$$

Where h_{req} = length of flexible skirting

h_{av} = average wave height

h_{100} = height of wave not exceeded with a probability of 1 in 100

Figure V-1 graphically presents the required skirted vehicle operating height versus significant wave height. An operating height of 3.0 feet is shown to be required in seas characterized by 3.5 foot significant waves.

c. Partially Skirted Vehicles

The wavy water operating height of partially skirted air wall vehicles is considered equal to their operating height over ground when measured from the mean sea level. This assumption follows from the analysis of unskirted air wall vehicles and is justified in the same manner.

SKIRTED AIR CUSHION LIGHTER VEHICLE
OPERATING HEIGHT AS A FUNCTION OF
SIGNIFIGANT WAVE HEIGHT

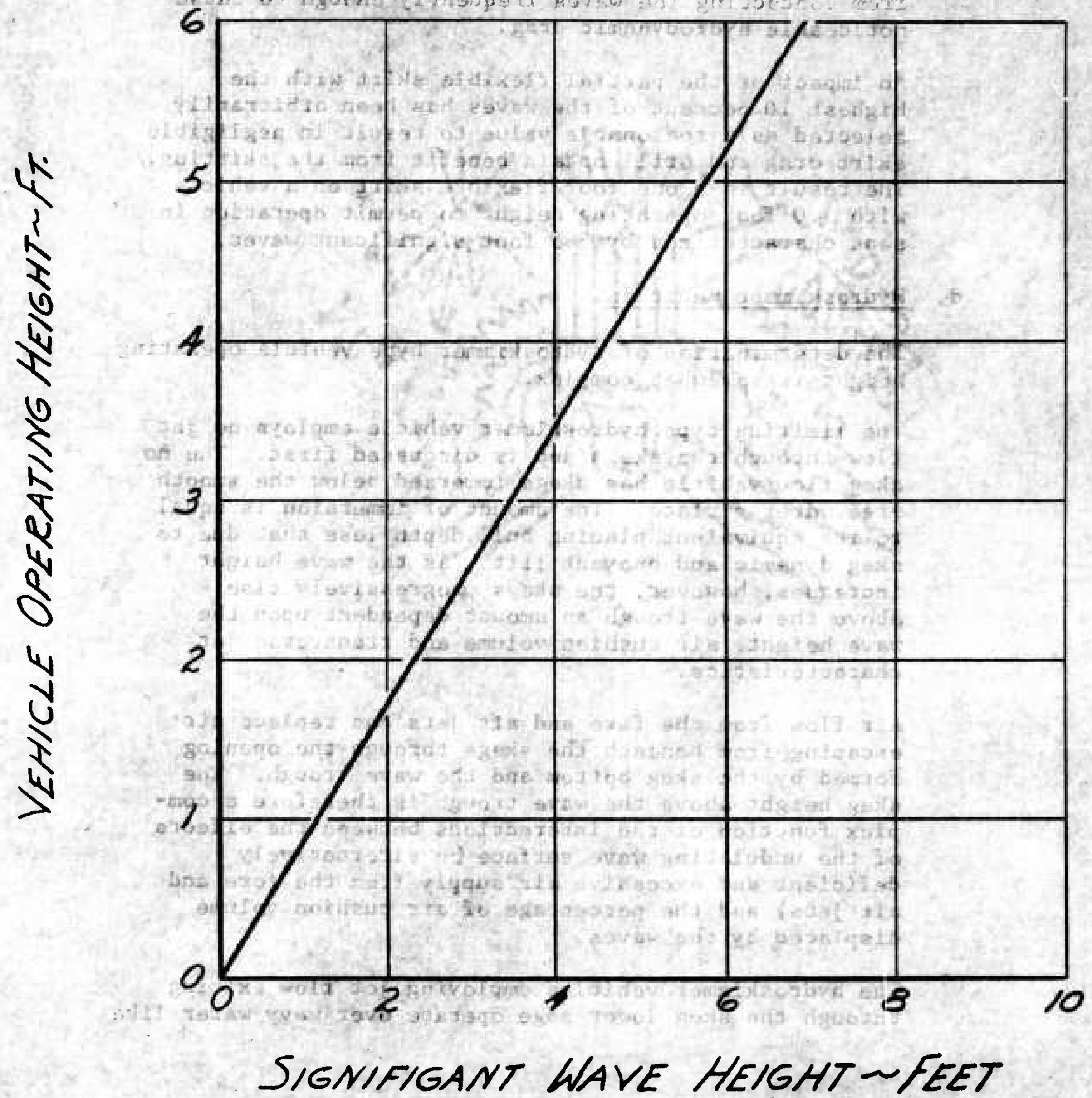


Figure V-1

In order for partially skirted air cushion vehicles to obtain benefit from the skirting, it is logical and necessary to permit their flexible skirts to impact waves more frequently than the hard structure. It is desirable, however, to keep the flexible skirt elements from contacting the waves frequently enough to cause noticeable hydrodynamic drag.

An impact of the partial flexible skirt with the highest 10 percent of the waves has been arbitrarily selected as a reasonable value to result in negligible skirt drag and still obtain benefit from the skirting. The result is a one foot flexible skirt on a vehicle with 3.0 foot operating height to permit operation in seas characterized by 3.5 foot significant waves.

d. Hydroskimmer Vehicles

The determination of hydroskimmer type vehicle operating height is somewhat complex.

The limiting type hydroskimmer vehicle employs no jet flow through the skegs and is discussed first. The no skeg flow vehicle has skegs immersed below the smooth free water surface. The amount of immersion is equal to its equivalent planing hull depth less that due to skeg dynamic and buoyant lift. As the wave height increases, however, the skegs progressively rise above the wave trough an amount dependent upon the wave height, air cushion volume and transverse jet characteristics.

Air flow from the fore and aft jets can replace air escaping from beneath the skegs through the opening formed by the skeg bottom and the wave trough. The skeg height above the wave trough is therefore a complex function of the interactions between the effects of the undulating wave surface (on alternatively deficient and excessive air supply from the fore and aft jets) and the percentage of air cushion volume displaced by the waves.

The hydroskimmer vehicles employing jet flow exiting through the skeg lower edge operate over wavy water like

air wall vehicles once the flat surface operating height of the skeg equals or exceeds half the wave height.

At skeg heights equal to or exceeding the half wave height the wavy water operating height of hydroskimmer vehicles with skeg jet flow are therefore equal to their ground operating heights when measured to the mean sea level.

The estimated heights of hydroskimmer vehicle skegs above the wave trough are presented on Figure V-2 as a function of the over ground skeg operating heights and sinusoidal sea heights. The hard structure base height required to clear waves whose height is not exceeded with a probability of 1 in 100 is

$$h_b = \frac{h_{av}}{2} - h_{s_t} + \frac{h_{100}}{2}$$

Where h_b = height of hard structure base measured from the lower edge of the skeg

h_{s_t} = height of skeg from average wave trough

It is possible, through the incorporation of transverse flexible skirts, to reduce the lifting air flow and power requirements of hydroskimmer vehicles. Use of such devices has been indicated earlier in this report. In order to determine the transverse jet exit height to obtain a given probability of flexible skirt wave encounter, the foregoing expression is used with substitution of the appropriate wave height (h_x) in place of the value of h_{100}. The length of flexible skirting required is then obtained as the difference between the h_b calculated with h_{100} and that calculated using h_x.

Skeg ground operating heights, varying from .0 to .75 feet were explored. The ratios of transverse jet exit to skeg heights were varied to result in transverse jet exit heights of from 2.0 feet to 4.5 feet. The lowest transverse jet exit height was selected to permit an average of no more than 1 out of 10 waves to impact the transverse jet skirting during operation in seas characterized by 3.5 foot significant waves.

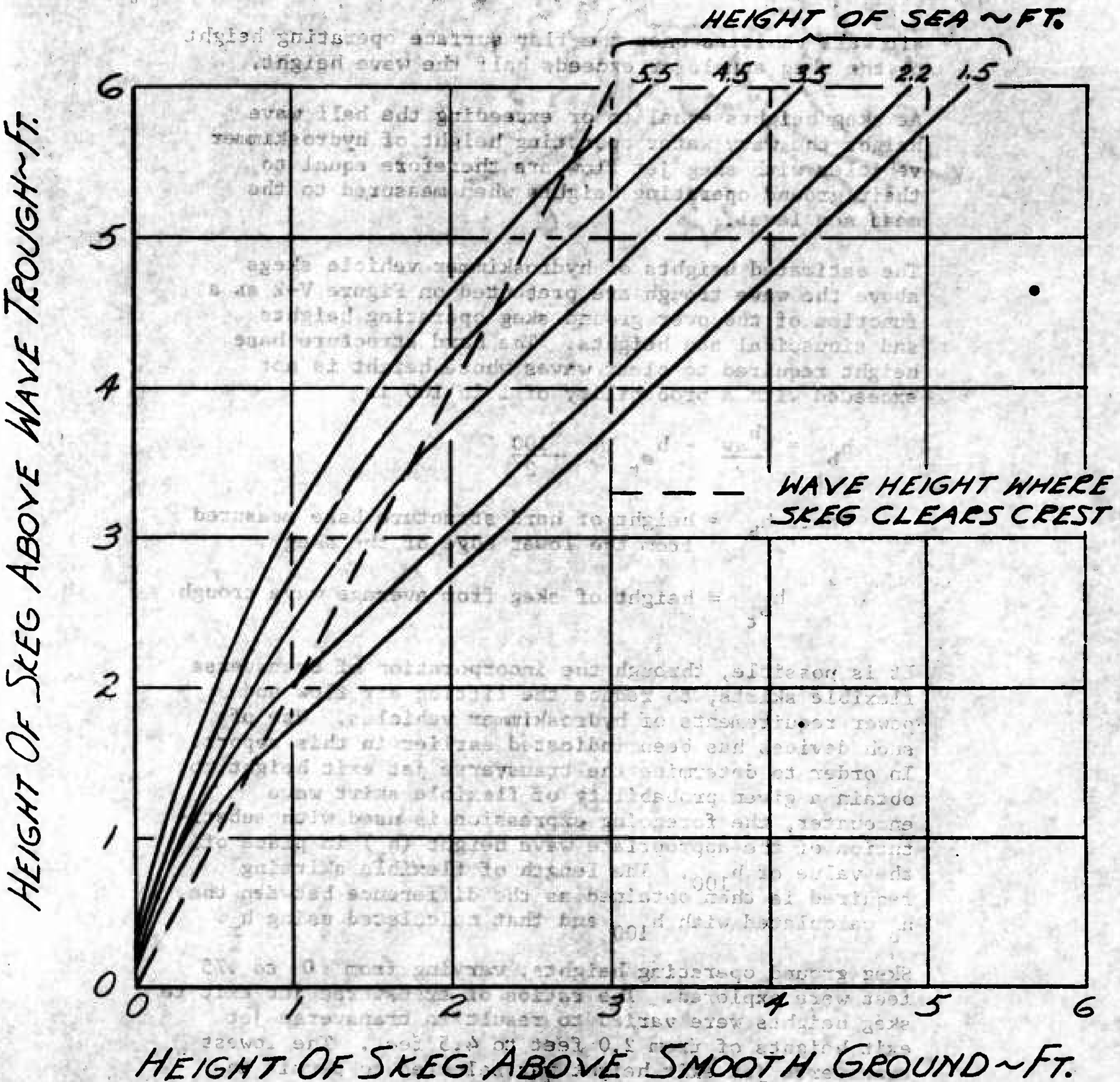


Figure V-2. Hydroskimmer Operating Height in Sinusoidal Seas of Varying Heights.

An intermediate ratio of transverse jet exit height to side skeg height was selected to permit clearance of a 5.5 foot wave crest without skirting of the transverse jets, (height of wave not exceeded more than 1 percent of the time during operation over seas characterized by 3.5 foot significant waves). The highest ratio of transverse jet exit height to side skeg height was arbitrarily selected to permit a 4.5 foot ground clearance at the transverse jet exit.

6. OPERATING HEIGHT OVER LAND

The air cushion vehicles are required to posess sufficient hard base structure obstacle clearance for overland travel with a minimum of route preparation. This requirement is not necessarily compatible with obtaining hard structure clearance of all but the highest 1 percent of the waves in seas with 3.5 foot significant waves.

Discussion of the overland obstacle clearance requirement for obtaining adequate ground mobility appears in Section III of this report. A value of 3.0 feet is indicated to be desirable for minimum route scouting and is selected as the hard structure operating height requirement for air cushion vehicles of this study.

Fortunately, the over ground operating height requirement is compatible with the partially skirted and fully skirted vehicle wavy water requirements in seas with 3.5 foot significant waves.

The unskirted pure air wall air cushion vehicle is required to operate at a height .25 feet higher than that required by seas with 3.5 foot significant waves.

The hard structure ground operating height of the amphibious hydroskimmer vehicles is dependent upon the height of skeg which can be retracted, the amount of skirting employed on the transverse jets and the vehicle lift flow and power characteristics. A complex iterative procedure is required to insure that the lift flow and power characteristics are compatible for both the overland obstacle clearance with skegs retracted and wavy water capabilities with skegs extended. Additionally, it is possible to expose or extend porous or non-porous flexible skirting along the

vehicle's sides when the skegs are retracted. Indeed, in the limiting case the skegs are permanently replaced by flexible skirting. The complexity of the matching procedure precludes determination of the overland operating height for all possible combinations. Rather, it is assumed the skeg is replaced by flexible skirting for overland travel.

7. DRAG ESTIMATES

Air cushion vehicles at forward speed experience drag from the following sources; in overland travel:

(1) Internal flow momentum drag

(2) External aerodynamic form drag

(3) Ground resistance from possible contact of vehicle elements with the surface (e.g. flexible skirts, brush, etc.)

(4) Drag due to external aerodynamic lift and that due to base tilt.

Additional to the foregoing, operation over water at forward speed causes hydrodynamic drag of the following types:

(1) Displacement or planing wave drag

(2) Spray drag

(3) Friction and form drag for vehicles employing elements in contact with the water (e.g. flexible skirts and skegs).

a. Momentum Drag

The momentum drag calculation procedure for the various vehicle types has been indicated earlier in this Section. Briefly summarized, the vehicle's momentum drag is the summation of momentum deficit, with respect to the free stream, of air exiting around the vehicle's periphery.

b. External Aerodynamic Drag

External aerodynamic form drag arises from friction of the air passing over and around the vehicle plus the resultant external air pressure forces acting to retard

the vehicle. Precise estimation of external aerodynamic drag is dependent upon exact knowledge of configuration shape, appendages and surface irregularities. Detailed estimation of external drag for all configurations investigated is not consistant with the intent of the study. Further, analysis reveals that the external aerodynamic drag exerts small influence on the total power requirements at operating speeds of interest in this study.

Wind tunnel tests of air cushion vehicles (References 16 and 25) show external aerodynamic form drag coefficients based on planform area varying from .03 to .10 for typical air cushion vehicle configurations. An assumed external aerodynamic drag coefficient of .05, based on vehicle planform area, was selected for use with all vehicles studied.

c. Ground Contact Drag

Drag resulting from air cushion vehicle elements contacting the ground was neglected for all vehicles considered. Excepting the skirted air cushion vehicle, drag resulting from ground contact will not occur except during occasional contact of partial flexible skirts with a higher than average obstacle.

The flexible skirt elements of the fully skirted vehicle are anticipated to operate some nominal distance clear of a smooth hard surface (e.g. one-half inch). Operation over typical terrain will result in frequent skirt contact with the ground. Point contact of the skirt element is assumed. During such contact the skirt element is deflected and experiences a resultant force which has components in both the lift and drag directions.

It is assumed, for the purpose of this study, that the savings in lift power resulting from the lift components of the resultant ground contact force is sufficient to balance its drag component. (Reference 47)

Experimental tests to determine the lift and drag characteristics of several flexible skirt element designs over representative terrain features are planned at the contractor's facilities in late 1961 and will continue into 1962. Results of these tests will permit more

accurate estimation of forces arising from contact of flexible skirt elements with the ground.

d. Aerodynamic Lift Induced Drag

Drag can also arise from external aerodynamic lift and tilt of the vehicle planform. A nose up attitude, tilting the lift vector aft, will produce a drag proportional to the sine of the tilt angle. Additionally, external aerodynamic lift can cause increased lifting air flow requirements by reducing the static air pressures around the vehicle's periphery. The net result is a drag component which must be overcome. It is important, therefore, that the air cushion vehicle be operated at the pitch attitude which results in obtaining its maximum lift-to-power ratio.

The precise estimation of the proper attitude versus speed for maximum lift-to-power of each vehicle studied is not within the scope of this study. It has been assumed, therefore, that the vehicle is operated at a zero degree pitch attitude and that no external aerodynamic lift is realized. Wind tunnel tests of a model of a particular peripheral jet air cushion vehicle (Reference 25) indicate this assumption is conservative.

e. Displacement or Planing Wave Drag

Air cushion vehicles operating over water experience drag akin to that of a planing hull craft. At low speeds this drag arises from the effective displacement of the vehicle and appears as wave making drag. The large range of vehicle planform loadings investigated precludes analysis of this drag component for each vehicle. Additionally, it was anticipated (and borne out by the study results) that the vehicles would operate at speeds analagous to achieving planing hull operation.

Air cushion vehicle hydrodynamic displacement drag at high speeds results from the angled depression appearing beneath the vehicle. The depression depth and its angle

are a function of vehicle planform loading (W/S), lift versus angle of attack characteristics ($C_{L\alpha}$) and relative dynamic water pressure (q_w). At relatively light planform loadings (W/S $\approx$ 20 Lb/Ft^2) and high forward speeds (V $\approx$ 80 knots) the relative dynamic water pressure (q_w = 18,200 Lb/Ft^2) produces negligible depression (.001 Ft) and depression angles (α = .08°).

Based on the results of earlier studies (Reference 24), it was anticipated (and later borne out) that the most economical pure air wall and partially skirted air wall vehicles would operate at high speed and have relatively low planform loadings. The drag resulting from hydrodynamic displacement was, therefore, neglected for air cushion vehicles employing the pure peripheral jet concept and partially skirted concepts.

Rudimentary preliminary analysis indicated that vehicles employing flexible skirting to the ground or skegs would have higher planform loadings and operate at lower speeds than the air wall types. Assuming a planform loading of approximately 64 Lb/Ft^2 and speed of 40 knots (q_w = 4550 Lb/Ft^2) the water depression and the depression angle of these vehicles would approximate .014 feet and 1.0 degrees, respectively. The hydrodynamic displacement drag of such a vehicle would equal 1.2 pounds per square foot of planform area (750 lb for a vehicle weighing 40,000 lb), -- not a negligible quantity.

The water spray, friction and form drag of fully skirted type vehicles are not readily generalized. Flexible skirt behavior over wavy water is dependent upon shape, mass, air cushion pressure loads and skirt element load-deflection characteristics amongst other things. The wetted area and angle of repose of each skirt element in the water is influenced directly by its stiffness and water dynamic pressure. Skirt elements which have lightly damped dynamic characteristics are likely to contact the water only intermittently.

Rudimentary estimates of flexible skirt water drag coefficient were accomplished by analysis of several possible flexible skirting elements and a probable

range of vehicle configuration characteristics. The assumed total hydrodynamic drag coefficient variation of fully skirted vehicles is presented on Figure V-3 as a function of significant wave height and is based on vehicle planform area. Additionally the assumed operating height with significant wave height variation shown on Figure V-1 is implicit in the presented drag assumptions. Included in the water drag coefficient variation are allowances for hydrodynamic wave, spray, friction and form drag components. Recognizing the crudeness of the assumed variation, the sensitivity of vehicle characteristics to drag coefficient was determined by variation of the drag coefficient from one-third the assumed values to double the assumed values. The results of this investigation are discussed in Section V-F of this report.

The hydrodynamic drag coefficient of hydroskimmer type vehicles is dependent upon many of the factors discussed previously for the skirted vehicle type. The principal drag differences between fully skirted vehicles and hydroskimmer type configurations arise from possible peripheral jet flow exiting the skeg (changing the skeg wetted area) and the differences in friction, spray and form drag between flexible skirts and rigid skegs. The assumed hydrodynamic drag coefficient of hydroskimmer type vehicles shown on Figure V-4 was estimated for seas characterized by 3.5 foot significant waves and is based on vehicle planform area. The assumed drag coefficients shown on Figure V-4 include allowances for hydrodynamic wave, spray, friction and form drag.

8. MANEUVERABILITY AND CONTROL

Accepted criteria defining required maneuverability of air cushion vehicles do not exist. Section III D of this report exposes possible maneuver requirements to be placed upon air cushion vehicles in LOTS operations. A maneuver criterion of 0.25 'g' at design height and speed is shown to be a reasonable design value for lateral and longitudinal acceleration requirements. Additional maneuver capability to approximately .5 'g' is indicated to be desirable for unusual situations. It is anticipated that maneuver capability in excess of .25 'g' can be achieved by transfer of lift power to control elements and/or permitting reduced operating height during unusual maneuvers.

SKIRTED AIR CUSHION LIGHTERAGE VEHICLE
WATER DRAG COEFFICIENT
BASED ON VEHICLE BASE AREA
VARIES WITH SIGNIFIGANT WAVE HEIGHT

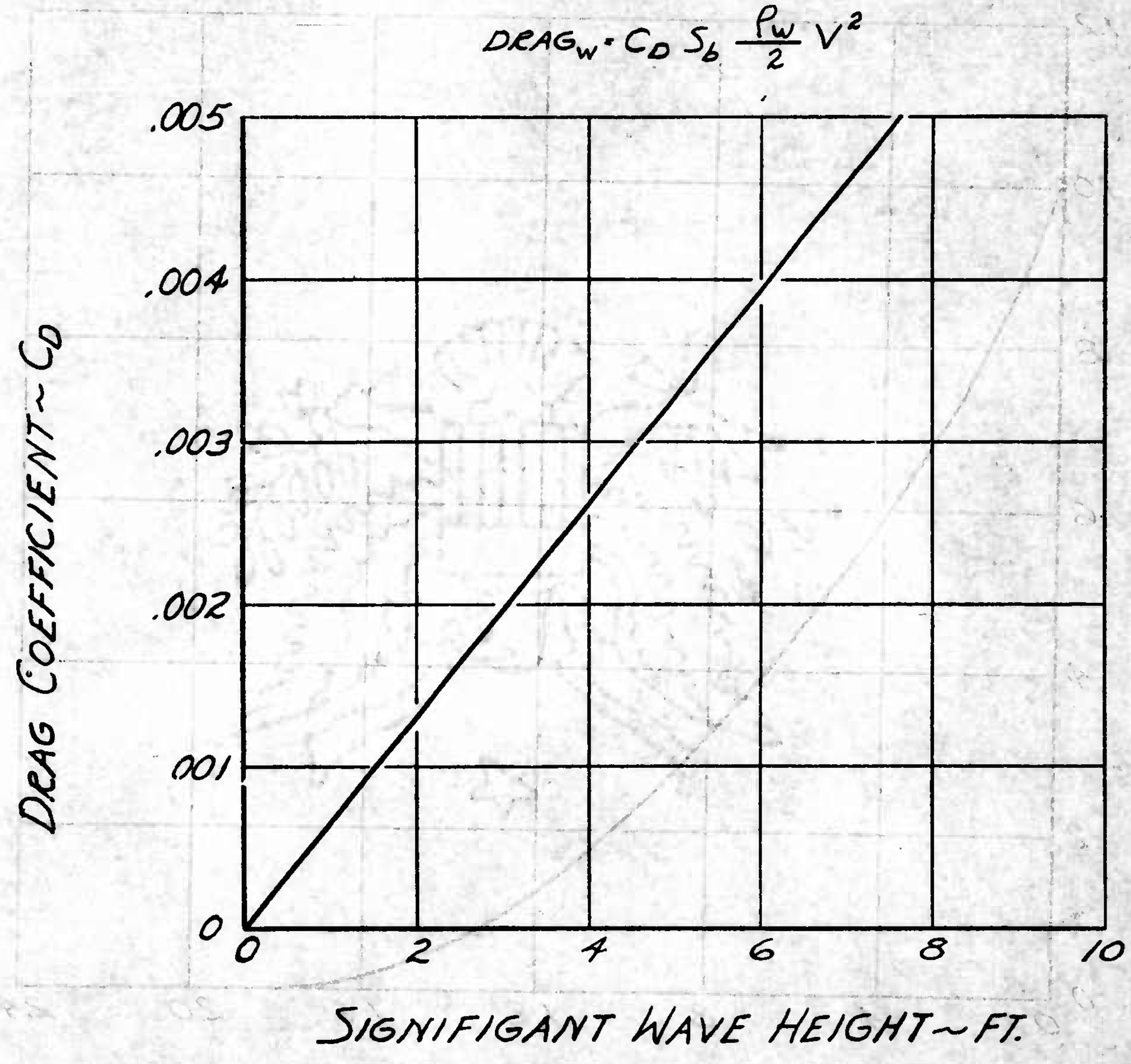


Figure V-3

HYDROSKIMMER WATER DRAG COEFFICIENT
3.5 FT. SIGNIFICANT WAVES ~ BASED ON
VEHICLE BASE AREA

$$DRAG_W = C_D S_b \frac{\rho_w}{2} V^2$$

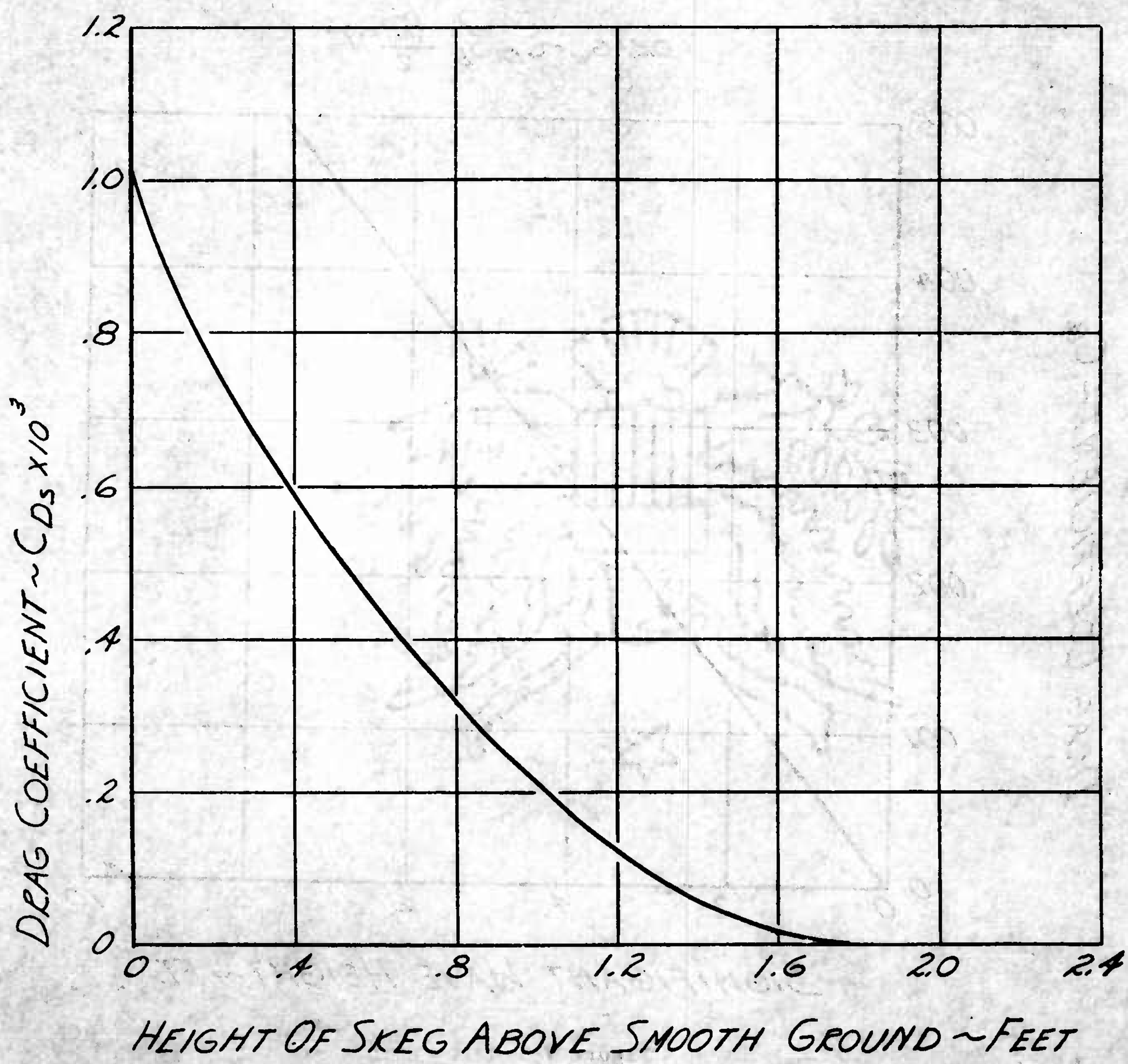


Figure V-4

A lateral maneuver requirement of .25 'g' at design speed, gross weight and operating height was, therefore, placed on all vehicles. Additionally, a longitudinal maneuver requirement of .25 'g' was placed on all vehicles at design gross weight during hovering at design operating height.

The maneuver capability was assumed to be obtained through use of propulsion effort. The power plant(s) supplying propulsive effort for maneuver is assumed capable of providing power for lift and propulsion as well.

Control of the propulsive forces for maneuver is assumed to be obtained through variable area and variable angle louvered ports located in the vehicle sides or through externally mounted and swiveling variable pitch, ducted fans. A specific static thrust of five pounds per shaft horsepower for maneuver was assumed to be obtainable for producing lateral forces at forward speed. Longitudinal acceleration capability is permitted to decay with increasing forward speed while deceleration capability increases.

Yaw control at low speed is obtained through either differential deflection of louvered ports on opposing vehicle sides or differential pitch and/or swivel of laterally positioned external ducted fans. Roll control is assumed to be obtained in a manner similar to yaw control.

Positive yaw stability of the air cushion vehicle at low forward speeds (less than 10 knots) is not considered as important as good yaw control. At low speeds neutral or slightly stable directional characteristics can be beneficial in permitting rapid and precise maneuvers. At higher forward speeds some margin of yaw stability is thought desirable. It is important however to keep the yaw stiffness of the vehicle consistent with yaw control powers so that response of the vehicle to crosswinds and gusts does not exceed the operator's ability to apply corrective control. Yaw stability at forward speeds can be provided by aft mounting of ducted propulsion control fans and/or vertical aerodynamic stabilizing and control surfaces. All vehicles investigated in this study are considered to have either external ducted fans and/or vertical aerodynamic surfaces to achieve desired yaw stability at high forward speeds.

Pitch trim of the vehicle is assumed to be obtained through tilt of louvered points in the fore and aft vehicle sides or through tilt of the externally mounted ducted fans.

9. PROPULSION

Propulsion for acceleration and deceleration is assumed to be obtained through the louvered ports or external ducted fans also used for maneuver. A propulsion system efficiency (η_p) of .75 at design speed was assumed. The effects of a lower (.5) propulsion system efficiency on vehicle characteristics was also determined.

The lifting air volume and pressure requirements were assumed to be obtained with a fan-duct system having component efficiencies of .85 and .8 respectively. A 98 percent recovery of free steam dynamic head was assumed to be obtained at the lifting fans.

Integration of the power plant(s) so that it can provide power simultaneously and in varying proportions to both lift and propulsion-maneuver elements of the propulsion system is assumed. Integrated power plant arrangements are desirable to minimize the total installed power, but can result in complex shafting and gearbox arrangements. Rudimentary air cushion vehicle designs incorporating integrated power plant arrangements are reported in References 24 and 29. Additionally the British SRN-2 Hovercraft, which is to be tested shortly, incorporates an integrated power plant arrangement.

Propulsion system weight was assumed to be 1.4 pounds per installed shaft horsepower with use of shaft turbine power plants. This assumption includes the weight of power plant, fans, gearboxes and shafting and is based upon the planning factor estimates provided by Curtiss-Wright (Reference 30) and verbally transmitted estimates from other well known propulsion system component manufacturers.

The estimated propulsion system component weights are:

(1) power plant - .35 pounds per shaft horsepower

(2) fans - .35 pounds per shaft horsepower

(3) gear boxes - .35 pounds per shaft horsepower

(4) shafting - .35 pounds per shaft horsepower

The effects of a higher (2.0 pound per shaft horsepower) propulsion system weight were investigated to determine the effects of propulsion system weight on vehicle characteristics.

Based on data for representative shaft turbine engines (Lycoming T-55) a specific fuel consumption of .75 pounds per shaft horsepower per hour was also assumed. The assumed specific fuel consumption is higher than the specific fuel consumption normally advertised for light weight shaft turbine engines to account for partial power operation and a 5 percent allowance for performance degradation in continued use.

Investigation of aircraft type reciprocating engine powered air cushion vehicles of the fully skirted and partially skirted air wall types was conducted. A propulsion system weight of 2.5 pounds per installed shaft horsepower and a specific fuel consumption of .5 pounds per shaft horsepower were assumed for the reciprocating engine powered vehicles. The assumed reciprocating engine powered propulsion system weight reflects the higher specific engine weight of the type (1.2 pounds per shaft horsepower) and higher fan, gearing, mounting and shafting weights (approximately 25 percent increase) due to impulse loadings imposed by reciprocating power plants. Investigation of diesel and industrial type spark ignition reciprocating type power plants were not considered due to their higher weights.

10. STRUCTURE

The structure of air cushion vehicles employed in LOTS operations must be compatible with its operational environment. Prominent among the design load criteria defining required structural integrity are:

(1) Ship-lighter contact loads during shipside loading.

(2) Cargo compartment loads imposed by cargo loading from ship's booms with relative ship-lighter movement present.

(3) Water impact loads occurring during design sea environment conditions (impact with the highest 1 percent of waves in seas characterized by 3.5 foot significant waves).

(4) Cargo tie down loads occurring during wavy water operation (positive 2.5 to 5.0 'g' vertical and negative 1.0 vertical at vehicle center of gravity; 8.0 'g' vertical at vehicle bow; 1.0 'g' lateral and longitudinal). (Reference 22)

(5) Rough terrain set down loads imposing point contact loads on vehicle structure.

(6) Hoisting loads for vehicle embarkation and debarkation aboard ship.

(7) Handling loads in cargo compartment during cargo positioning for proper vehicle center of gravity.

(8) Aerodynamic loads on vehicle base and external contour.

(9) Handling loads during maintenance operations.

(10) Water impact loads arising from unanticipated water contact due to power failure.

(11) Water loads imposed by displacement operation in wavy water.

Detail investigation and design studies to generate vehicle structure weight variation as a function of planform loading have not been accomplished to date. This type of information is required in order to permit reasonably accurate estimates of vehicle structure weight for each type of vehicle considered.

Rudimentary analysis of air cushion vehicle structure and resulting weights have been reported in References 22, 29, 31 and 32. The specific structural weights shown in the foregoing References vary from a low of approximately 4 pounds per square foot to approximately 20 pounds per square foot. The wide spread in unit structural weights results from many diverse factors, not the least of which are:

(1) Varied structural design criteria.

(2) Air cushion flow concept and vehicle configuration.

(3) Planform loading.

A nominal structural weight variation with planform loading was assumed. The assumed structure weight variation attempts to account for the variations in occasional hydrodynamic impact loadings with forward speed with the implicit assumption that higher speed vehicles will tend toward higher planform loadings. Additionally, it reflects an interpretation of unit structure weights presented in the cited references.

The assumed nominal structure weight variation in terms of fraction of vehicle gross weight $\left(\frac{W_s}{W_G}\right)$ is analytically expressed as

$$\frac{W_s}{W_G} = \frac{2 + .67\ (W/S)^{\frac{1}{2}}}{W/S}$$

Where W/S is planform loading (also called L/S)

The nominal structure weight variation expressed above and the variation representing a 50 percent increase in structure unit weight is graphically presented on Figure V-5.

11. FIXED EQUIPMENT

Fixed equipment in the amount of 1,000 pounds was assumed for all vehicles investigated. This nominal weight allowance to cover various items of communication, control and instrument equipments found in the crew compartment.

12. COSTING ASSUMPTIONS

a. Structure

Structure costs were nominally assumed at six dollars ($6.00) per pound. Selection of this value is predicted on the assumption of welded aluminum construction. A value of fifteen dollars ($15.00) per pound was also utilized to expose the effects of structure costs on air cushion vehicle costs and characteristics. The specific structure costs are applied to the sum of structure and fixed equipment weights to determine total structure costs.

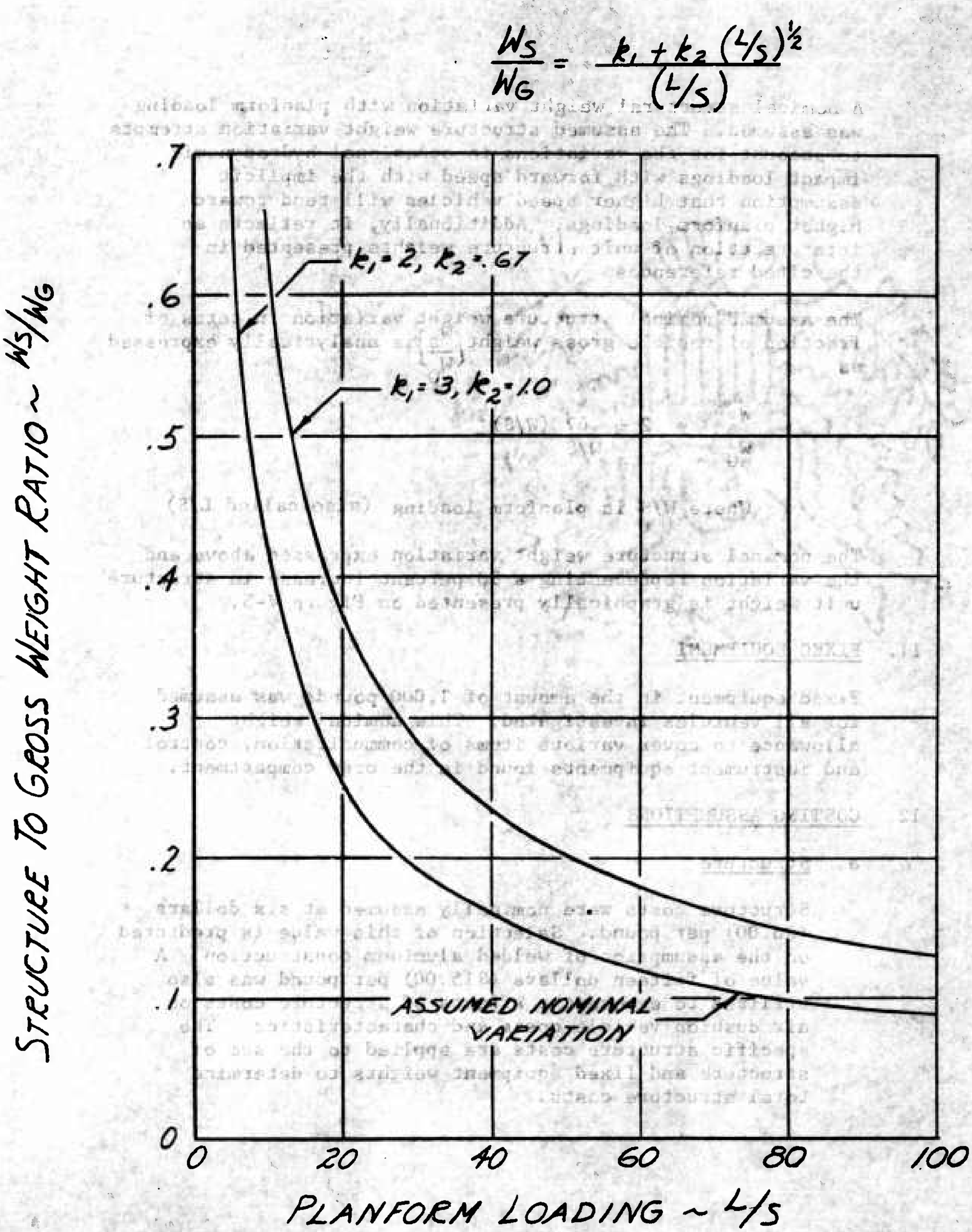


Figure V-5. Air Cushion Lighterage Vehicle Structure Weight Ratio.

b. Propulsion

The propulsion system cost of each vehicle was computed on the basis of total installed power (shaft horsepower). Specific propulsion system cost was nominally assumed at forty-three dollars ($43.00) per pound. This figure includes the cost of power plant, fans, gear boxes and shafting.

Based on the planning data provided by Curtiss-Wright (Reference 30) and other propulsion system component manufacturers, the component costs were estimated as follows:

(1) Turbine power plant at thirty-two dollars ($32.00) per shaft horsepower.

(2) Fans at three dollars ($3.00) per shaft horsepower.

(3) Gear boxes at fifteen dollars ($15.00) per shaft horsepower.

(4) Shafting, couplings and supporting brackets at ten dollars ($10.00) per shaft horsepower.

The resulting propulsion system cost of sixty dollars ($60.00) per shaft horsepower divided by the previously discussed 1.4 pound per shaft horsepower specific propulsion system weight yields a forty-three dollar ($43.00) per pound specific propulsion system cost.

The effects of specific propulsion system costs on vehicle characteristics were investigated by varying the assumed nominal value from a low of thirty-six dollars ($36.00) per pound to a high of fifty dollars ($50.00) per pound.

c. Fuel

Fuel costs for turbine power plants were estimated at two cents ($00.02) per pound.

The fuel consumption of each vehicle at its design cruise condition was utilized to compute its fuel costs.

d. MANPOWER

Manpower costs are predicted on the use of enlisted personnel since it is anticipated that a simple control system will be evolved for air cushion vehicles. The manpower requirement of each vehicle is based on its payload capacity in the following assumed manner:

2 man crew	0	to	49,999	pound payload
3 man crew	50,000	to	119,999	pound payload
4 man crew	120,000	to	200,000	pound payload

The crew complement selected are assumed consistent with manpower necessary for safe and efficient operation of the vehicle.

Crew costs are computed on the basis of fourteen dollars and thirty cents ($14.30) per man per day for a ten hour working period (Reference 5). An hourly crew charge of one dollar and forty-three cents ($1.43) per man was therefore, used.

The crew is considered available for stevedoring chores during loading and unloading operations. Additional stevedore personnel from the Terminal Service Company are assumed to be stationed aboard ship to perform the major portion of stevedoring chores. The costs of the latter personnel are not included in assessing vehicle manpower charges.

e. Initial Cost and Amortization

The initial cost of the vehicle was computed as the sum of propulsion system, structure and fixed equipment costs. Amortization of the vehicle's initial cost over an expected life of 10,000 hours permits proper inclusion of this factor in determining direct hourly charges resulting from its use. The assumed 10,000 hour vehicle life is consistent with the life credited to existing wheeled amphibious lighterage and helicopter equipments. (See Section VI of this report for additional discussion.)

f. Maintenance, Attrition and Utilization

Maintenance and attrition costs for air cushion vehicles are an unknown quantity at this time. Lack of operational air cushion vehicles precludes an accurate estimation of their maintenance requirements and probable attrition. It is anticipated that a concerted effort will be devoted to securing air cushion vehicles with minimum practical maintenance requirements to permit full utilization of their military potential. Maintenance cost and utilization of wheeled amphibious lighterage equipment reported in Reference 6 and 24 and discussed in Section VI of this report indicate that modest maintenance requirements can be achieved through careful design of the vehicles even though they employ sophisticated rotating machinery and power transfer boxes.

Attrition, as discussed in Section VI of this report, enters the cost computations in a manner similar to maintenance and is analytically interchangeable with it. The attrition costs are assumed as 5 percent of force per year and are included in the charges assessed air cushion vehicles in this study.

The data in References 6 and 24 were employed as a guide in estimating the nominal maintenance level, attrition and utilization of air cushion vehicles in this study. A nominal maintenance cost per year equal to 50 percent of vehicle initial cost was divided by the corresponding 4,750 hour annual utilization to determine the hourly maintenance charges. Maintenance costs ranging from 30 to 70 percent of vehicle initial cost were used to discern the sensitivity of vehicle characteristics to maintenance cost factors.

g. Daily Lighterage Costs

The method described in Section VI of this report was employed to determine the daily lighterage costs of air cushion vehicles for continuous servicing of one ship's hatch. The lighterage costs per ton delivered were computed by dividing the vehicle daily costs by the tonnage delivered per 20 hour working day.

Payload is carried from ship to inshore transfer point only. The return trip is made empty. The equations used in the computations are presented in Section VI of this report and are repeated here for completeness.

$$\text{Daily costs} = C_T \left(\frac{H}{P}\right) \left(\frac{40}{A}\right) \left(\frac{D_1}{V_1} + \frac{D_2}{V_2} + \Sigma M\right)$$

$$+ \frac{20}{A} \left[\left(\frac{H}{U}\right) k \,(.143) + C_T - .9\, C_F \right]$$

Where C_T is the total hourly direct costs of the lighterage vehicle in over water operation

C_F is the lighterage vehicle hourly fuel cost

k is the number of crew personnel

H is the hatch rate

U is the inland unloading rate

P is the vehicle payload

A is the vehicle availability

ΣM is the summation of maneuver times per cycle divided by two

It should be noted that the hatch rate, unloading rate and payload must be introduced to the equation in consistent units of either tons or pounds. Additionally, it is noteworthy that availability enters the equation as a multiplying factor, permitting comparison between vehicles to be accomplished with an availability of unity.

The assumptions and estimates employed in the air cushion vehicle analysis are summarized for ease of reference in Table V-1.

TABLE V-1

SUMMARY OF AIR CUSHION VEHICLE ASSUMPTIONS AND ESTIMATES

ITEM	NOMINAL VALUE	VARIATIONS
Overland Distance	5 n.mi.	0 to 10 n.mi.
Overwater Distance	25 n.mi.	5 to 75 n.mi.
Overland Speed	15 knots	0 to 35 knots
Overwater Speed	--	0 to 80 knots
Payload	--	5 to 25 tons
Size Constraint	35 ft.	19 ft. x 35 ft & 24 ft. x 60 ft.
Length to Width Ratio	2	1.84 & 2.5
Planform Loading	--	10 lb/ft^2 to 100 lb/ft^2
Maneuver Capability	.25 'g'	.1 'g' to .5 'g'
Propulsion System Efficiencies		
Duct	.8	--
Lift Fans	.85	--
Propulsion	.75	.5 & .75
Ram Recovery at Fan	.98	--
Peripheral Jet Variables		
Jet Thickness to Height Ratio	.35	.13 to .95
Jet Inclination Angle	15^{o}	--

TABLE V-1

(continued)

ITEM	NOMINAL VALUE	VARIATIONS
Jet Exit Static Pressures		
Front	Equal to free stream dynamic pressure	
Sides	Zero	
Rear	Negative one-half free stream dynamic	
Jet Thrust		
Front	Momentum drag computed	
Sides	Zero	
Rear	Momentum drag computed	
Intraventing Power	10 percent of lift plus momentum drag powers	
External Drag Coefficient	.05	--
Operating Height	3.0 ft.	.75 to 5.5 ft.
Skirted Vehicle Variables		
Skirt Discharge Coefficient	.1	--
External Drag Coefficient		
Aerodynamic	.05	--
Hydrodynamic	See Figure V-3	
In 3.5 ft. Sig. Waves	.00232	.0007 to .0035
Base to Plenum Total Pressure Ratio	.99	--
Jet Thrust	Momentum drag computed	

TABLE V-1

(continued)

ITEM	NOMINAL VALUE	VARIATION
Operating Height	3.0 ft.	.75 to 5.5 ft.
Power for Stability	10 percent of lift plus momentum drag power	
Jet Exit Static Pressures	Same as Peripheral Jet	
Hydroskimmer Vehicle Variables		
Jet Thickness to Height Ratio	.35	--
Jet Inclination Angle	15^{o}	--
Jet Exit Static Pressures	Same as Peripheral Jet	
Jet Thrust	Same as Peripheral Jet	
Intraventing Power	Same as Peripheral Jet	
External Drag Coefficient		
Aerodynamic	.05	--
Hydrodynamic	See Figure V-4	
Operating Heights		
Skegs	--	0 to .75 ft.
Transverse Jet Exits	Function of Skeg Height	2.0 ft. to 4.5 ft
Partial Skirted Variables		
Basic Variables	Same as Peripheral Jet	
Skirt Length	1.0 ft	--

TABLE V-1
(continued)

ITEM	NOMINAL VALUE	VARIATION
Weights		
Propulsion System	1.4 lb/SHP	1.4 & 2.0 lb/SHP
Structures	See Figure V	
Fixed Equipment	1000 lbs	--
Costs		
Propulsion System	$43/lb	$36/lb to $50/lb
Structure	$6/lb	$6/lb & $15/lb
Manpower	$1.43/hr/man	--
Attrition	5 percent initial cost/year	--
Maintenance	50 percent initial cost/year	30 % to 70 %
Fuel	$ .02/lb	--
Amortization of initial cost	10,000 hours	--

F. RESULTS OF AIR CUSHION VEHICLE ANALYSIS

The results of the air cushion vehicle studies are presented in graphic form. Results for individual vehicle types are presented first. Comparison of the vehicle types are then accomplished.

1. AIR WALL AIR CUSHION VEHICLE

Initial investigations of air wall air cushion vehicles as previously indicated in Section V-E of this report were directed at determining the influence of side jet thickness to height ratio (te/h) on vehicle costs.

The investigation of jet thickness variations was accomplished with singular requirements for payload (10 short tons), overwater distance (10 n. miles), land distance (5 n. miles) and land speed (15 knots). Overwater speeds varying from 10 to 80 knots and operating heights varying from .75 feet to 5.5 feet were investigated. The nominal assumptions presented in Section V-E of this report were employed in the jet thickness analyses.

The unlimited width minimum cost vehicles resulting from the te/h studies are presented on Figure V-6. Figure V-7 presents the results for minimum cost vehicles that are limited to a 35 foot maximum width. Figure V-8 is a comparison of the jet thickness study results for the cases of both limited and unlimited vehicle width at the speed resulting in overall minimum daily costs (80 knots).

Perusal of the data on Figures V-6 through V-8 reveals that, dependent upon speed and height of operation, use of side jet te/h values varying between .35 to .6 result in vehicles with minimum cost. Calling attention to Figure V-8 it is seen that use of side jet te/h's from .35 to .95 result in vehicles having negligible cost differences at the lower operating heights (less than 2.0 feet). At the higher operating heights a te/h value of .35 is shown to be more advantageous.

Further investigations of vehicles employing peripheral jets were based on an assumed side jet te/h value of .35 for the following reasons:

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 56% INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = 5[2+.67(L/S)^.5]; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 10 N.MI.; VARYING JET THICKNESS TO HEIGHT RATIO; PAYLOAD = 10 TONS; WIDTH NOT CONSTRAINED

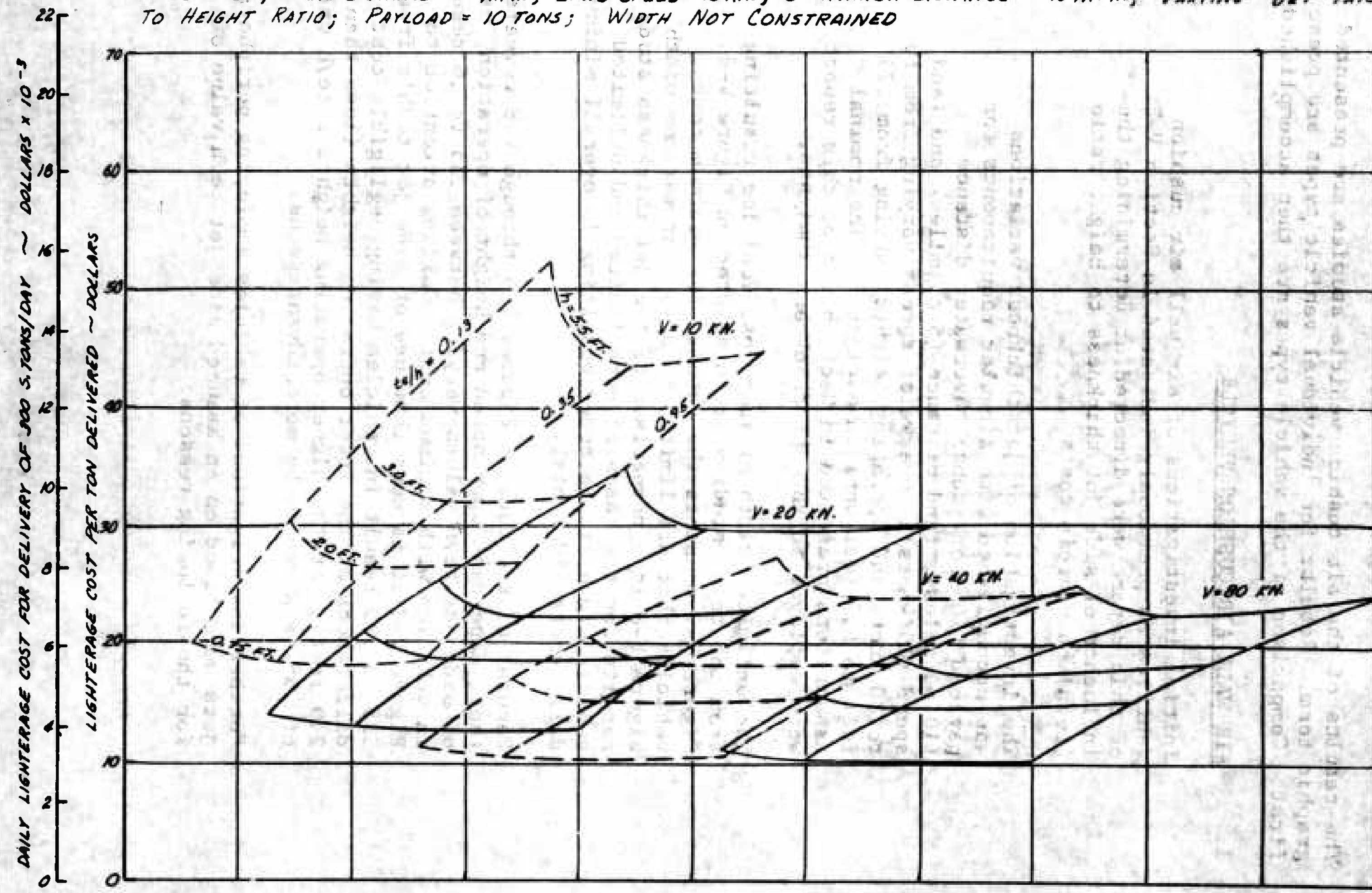


Figure V-6

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR/YR.; MAINTENANCE + ATTRITION = 55% INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB/SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = $S[2+.67(t/s)^{.5}]$; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 10 N.MI.; VARYING JET THICKNESS TO HEIGHT RATIO; PAYLOAD = 10 TONS; WIDTH CONSTRAINED TO 35 FEET

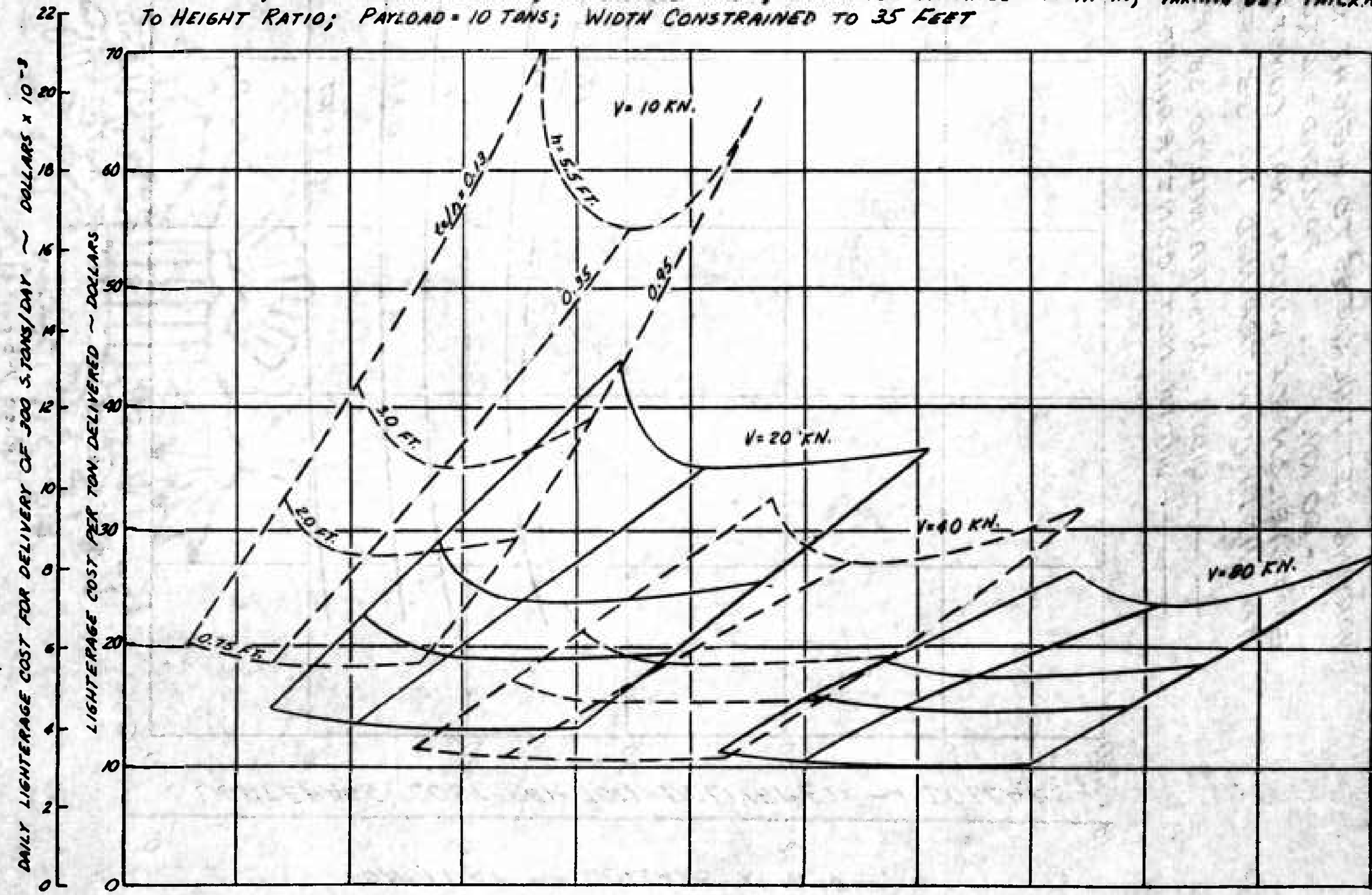


Figure V-7

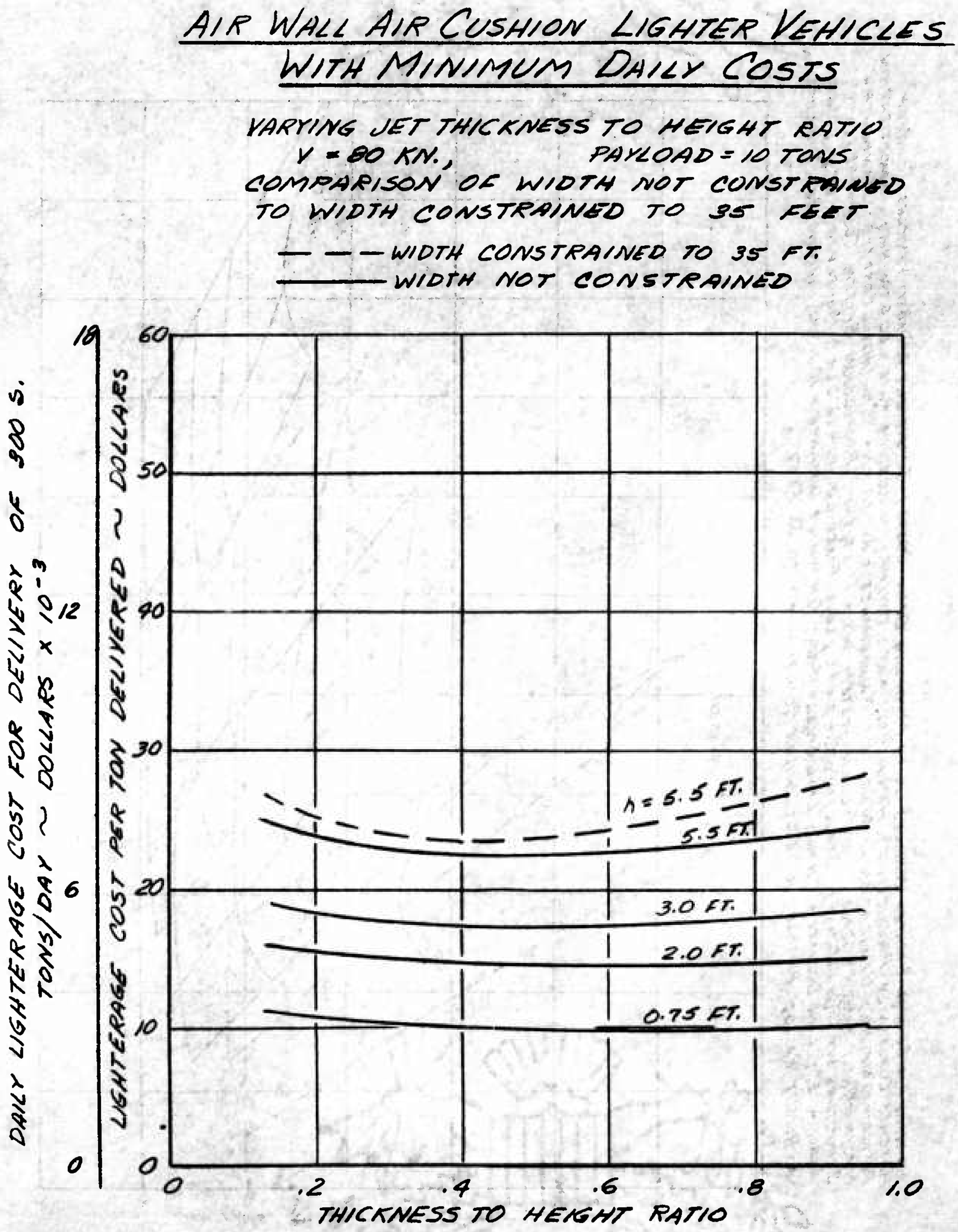

AIR WALL AIR CUSHION LIGHTER VEHICLES
WITH MINIMUM DAILY COSTS
VARYING JET THICKNESS TO HEIGHT RATIO
V = 80 KN., PAYLOAD = 10 TONS
COMPARISON OF WIDTH NOT CONSTRAINED
TO WIDTH CONSTRAINED TO 35 FEET
WIDTH CONSTRAINED TO 35 FT.
WIDTH NOT CONSTRAINED
DAILY LIGHTERAGE COST FOR DELIVERY OF 900 S. TONS/DAY ~ DOLLARS x 10^-3
LIGHTERAGE COST PER TON DELIVERED ~ DOLLARS
THICKNESS TO HEIGHT RATIO
h = 5.5 FT.
5.5 FT.
3.0 FT.
2.0 FT.
0.75 FT.
0
6
12
18
10
20
30
40
50
60
.2
.4
.6
.8
1.0

Figure V-8

(1) At the higher operating heights of interest a side jet te/h value of .35 results in vehicles with maximum economy.

(2) At all cruising speeds investigated and particularly at cruising speeds resulting in minimum daily costs, use of a side jet te/h value of .35 results in vehicles with superior economy.

(3) Investigations of inlet-fan-duct matching (References 22 and 26) indicate that use of low te/h values permit high efficiencies of the lift propulsion system to be obtained with relatively straightforward and simple arrangement of the propulsion system elements.

(4) The selected side jet te/h value permits good performance at off-design operating heights and/or speeds.

Studies of the inter-related effects of air wall vehicle payload, operating height, speed and mission radii are presented on Figures V-9 through V-15. Each point presented on these figures represents the vehicle having minimum daily cost at the particular combination of parametrically assigned speed, payload operating height and mission radii requirements.

Figure V-9 presents data for minimum cost air wall vehicles which are not limited to a maximum width of 35 feet and have a mission radius permitting 5 n. mile land travel and 5 n. mile overwater travel in each direction. Figure V-10 presents data for minimum cost air wall vehicles which are limited to a maximum width of 35 feet and have the same mission radii as those on Figure V-9.

The data on Figures V-9 and V-10 indicate that payloads of approximately 10 tons and speeds of 40 to 80 knots result in minimum daily cost for the servicing of one ship's hatch. Varying the water operating speed between 20 and 80 knots at the short mission radii is shown to produce small changes in daily costs at all but the highest operating heights. The insensitivity of cost results to overwater speed is to be expected in light of the large proportion of vehicle cycle time spent in

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4950 HR./YR.; MAINTENANCE + ATTRITION = 55 % INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = 5[2+.67(4/5)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 5 N.MI.; VEHICLE WIDTH NOT LIMITED

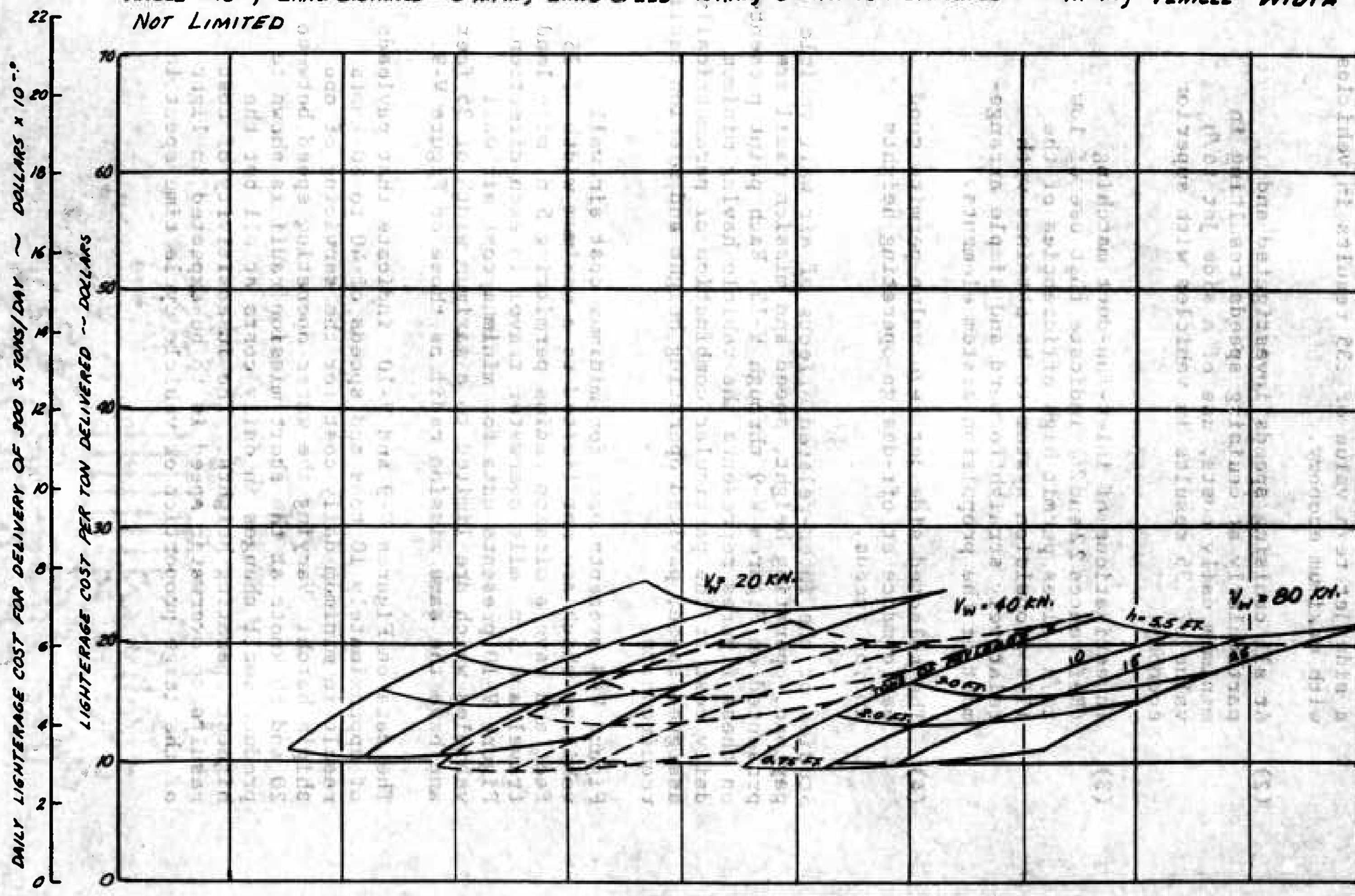


Figure V-9

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 55 % INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+.67(l/s)^-.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25'g'; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 5 N.MI.; l/h = .35; VEHICLES LIMITED TO 35 FT. WIDTH

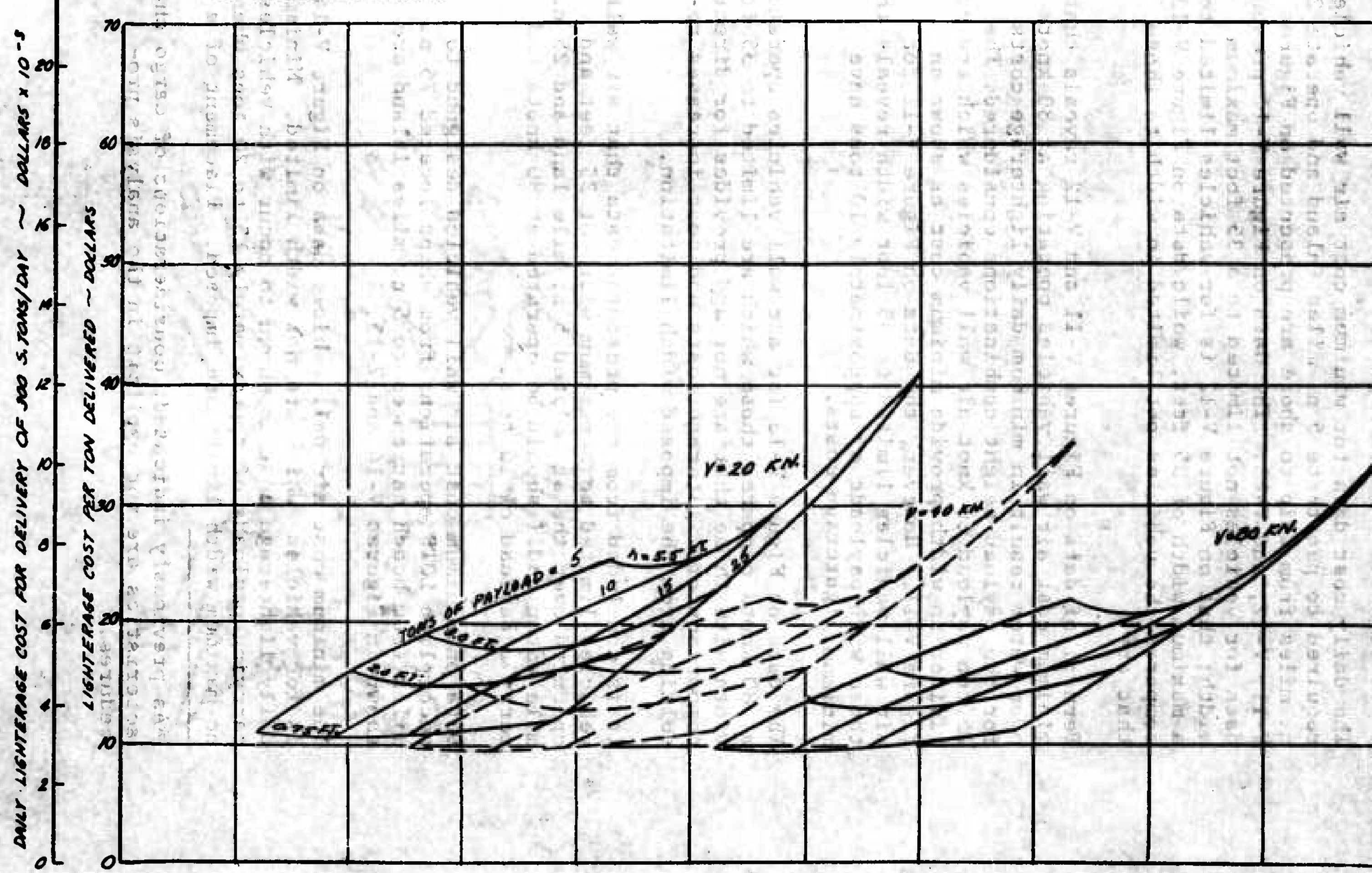


Figure V-10

cargo loading and unloading operations.

The daily cost data for minimum cost air wall vehicles required to penetrate 5 n. miles inland and operate 25 n. miles from ship to shore are presented on Figures V-11, V-12, and V-13. The data on Figure V-11 presents data for vehicles not limited to a 35 foot maximum width; that on Figure V-12 is for vehicles limited to a maximum width of 35 feet; while data on Figure V-13 compares the vehicles not limited in width to those that are.

Perusal of data on Figures V-11 and V-12 reveals that minimum cost air wall vehicles operating at 80 knots over water result in minimum daily lighterage costs for the payload-height combinations considered. The 15 ton payload 80 knot air wall vehicles which are not limited in width provide minimum cost as shown on Figure V-11. However, the data on Figure V-12 for air wall vehicles limited to 35 foot width reveals that those with payloads of approximately 10 tons have minimum lighterage costs.

The data on Figure V-13 for air wall vehicles operated at 80 knots compares those which are limited to 35 foot width with those that are not and provides for direct comparison of lighterage costs and cost increases resulting from the imposed width limitation.

It is concluded from the presented data that air wall vehicles limited to a maximum width of 35 feet and operated over the stipulated 5 n. mile land and 25 n. mile water radii should be operated at 80 knots and carry a payload of 10 tons.*

Data on minimum cost air wall vehicles designed to accomplish LOTS operations from ships located 75 n. miles from beach entrances to 5 n. miles inland are shown in Figures V-14 and V-15.

The minimum cost air wall vehicle data on Figure V-14 is for vehicles which are not width limited. Minimum daily lighterage cost is shown to occur with vehicles carrying payloads of approximately 15 to 20 tons when no maximum width limits are imposed. Placement of a

*As previously indicated, considerations of cargo characteristics are not explicit in the analysis procedures.

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 65 % INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = S[2+.67 (l/s)^.5]; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 'g'; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; lc/h = .35; VEHICLE WIDTH NOT LIMITED

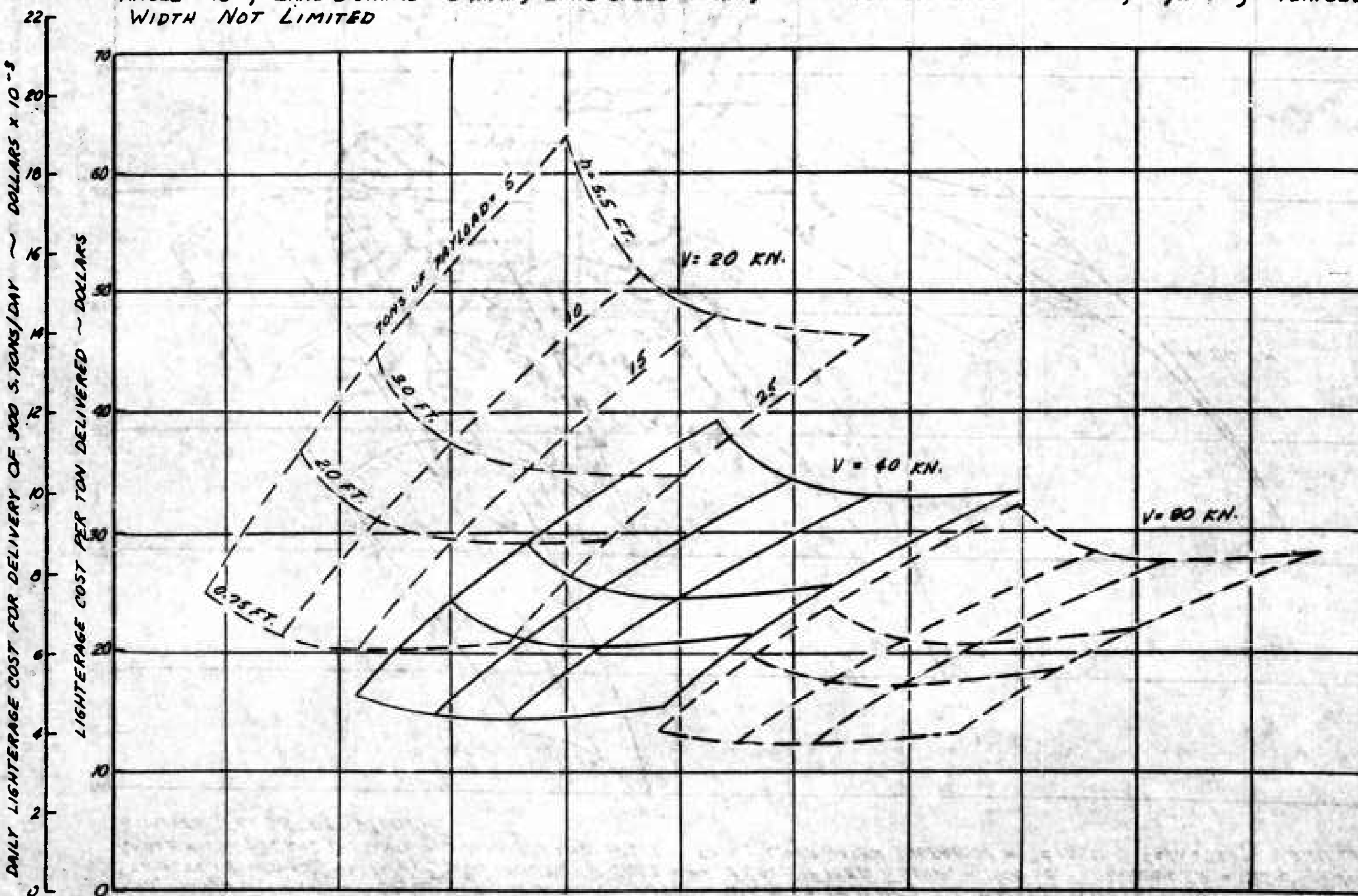


Figure V-11

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 55 % INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+.67(L/S)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; t_c/h = .35; VEHICLES LIMITED TO 35 FT. WIDTH

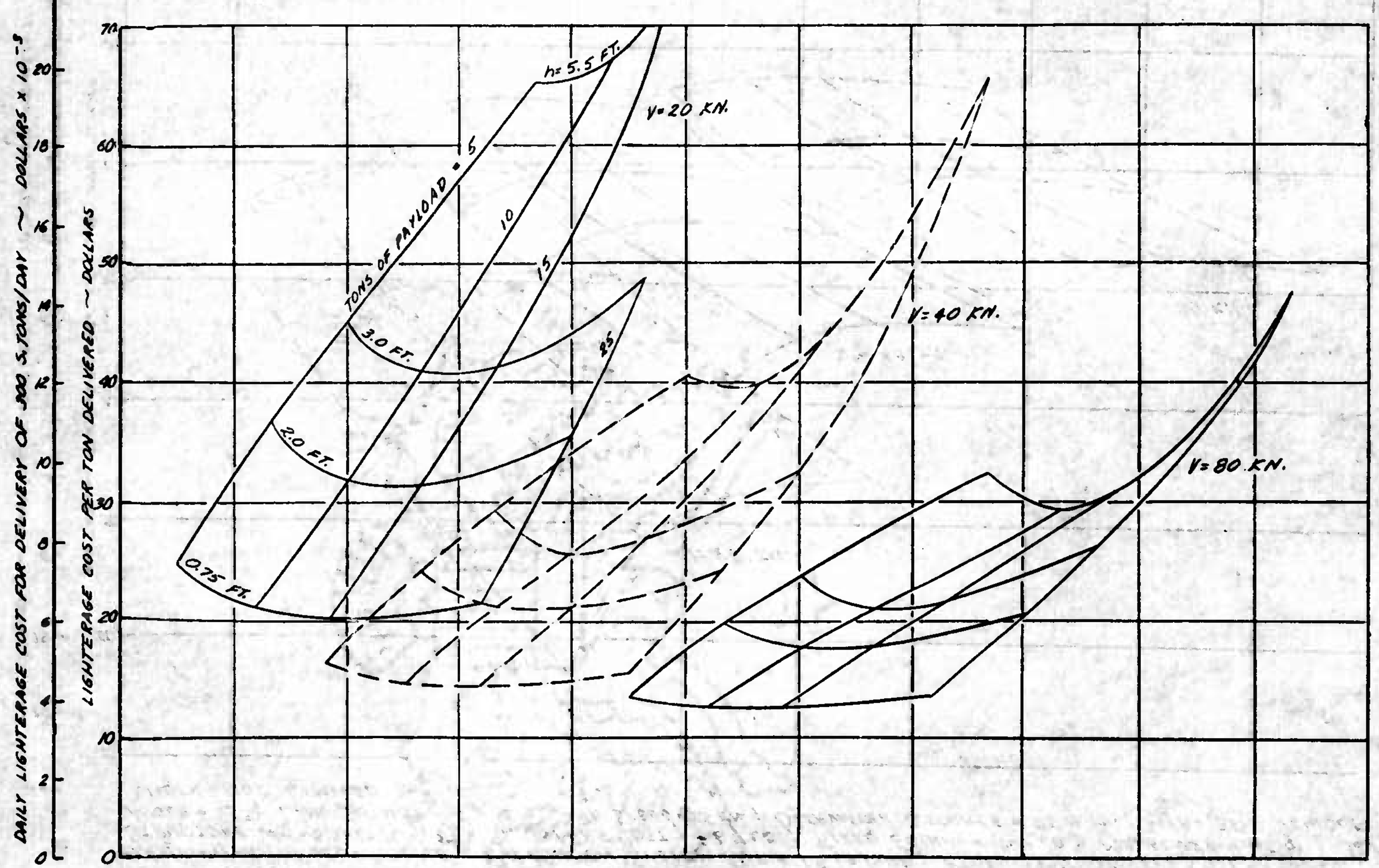


Figure V-12

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS

COMPARISON OF COST — VEHICLES WITH NO WIDTH LIMIT — VEHICLES WITH 35 FT. WIDTH LIMIT

$V = 80$ KN.

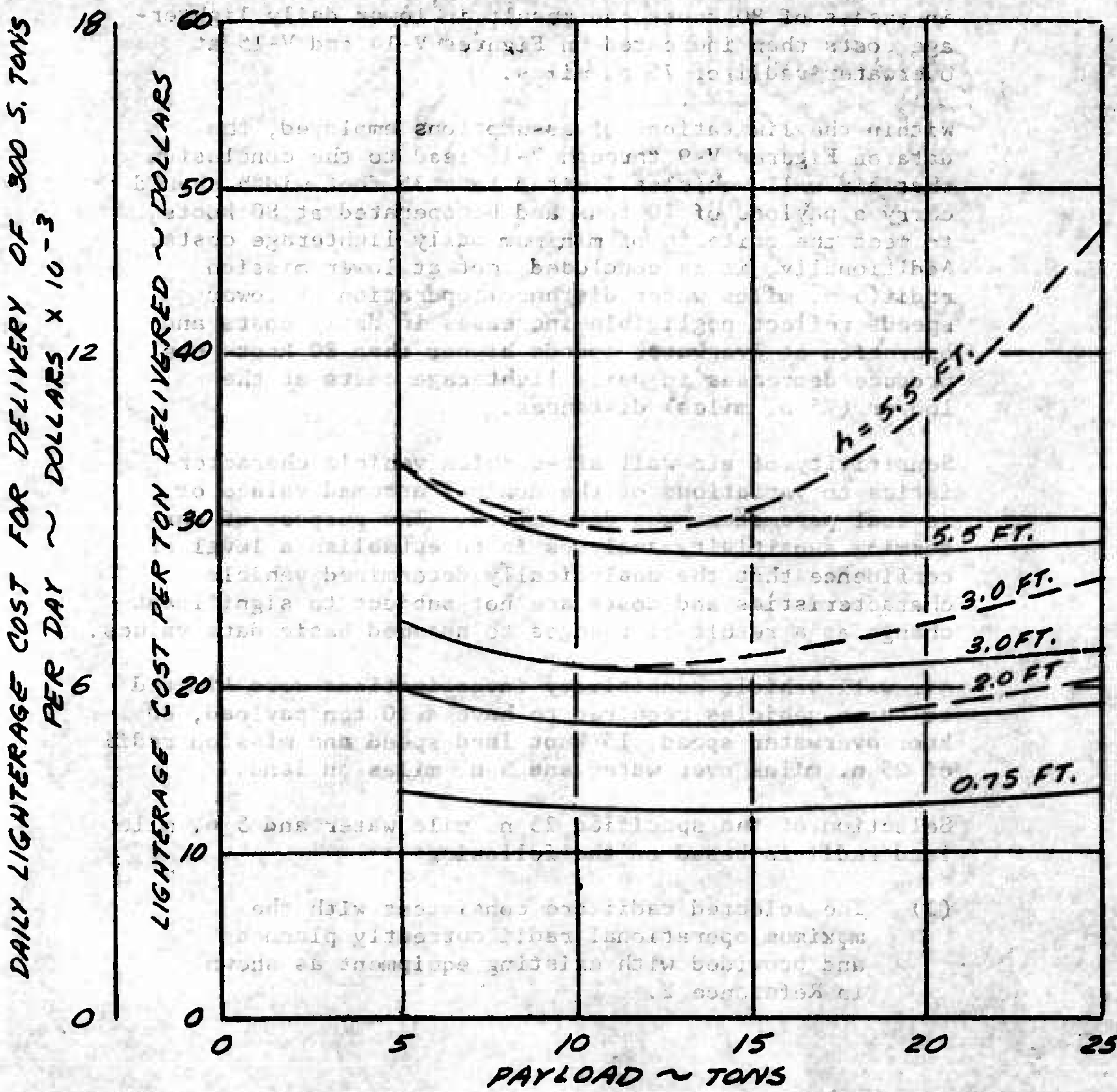


Figure V-13

35 foot maximum width limit on the air wall vehicles with 75 n. mile water radius causes a reduction in desirable payload to approximately 10 tons as shown on Figure V-15. Overwater operating speeds in excess of 80 knots are also indicated by Figures V-14 and V-15 to result in lower daily lighterage costs. Investigations of overwater speeds higher than 80 knots were not conducted due to the rather arbitrary establishment of 80 knots as a limiting practical speed for lighterage operation. It should be recognized that air wall vehicle operation at speeds in excess of 80 knots can result in lower daily lighterage costs than indicated on Figures V-14 and V-15 at overwater radii of 75 n. miles.

Within the limitations of assumptions employed, the data on Figures V-9 through V-15 lead to the conclusion that air wall vehicles limited to a 35 foot width should carry a payload of 10 tons and be operated at 80 knots to meet the criteria of minimum daily lighterage costs. Additionally, it is concluded that at lower mission radii(5 n. miles water distance) operation at lower speeds reflect negligible increases in daily costs and operation at overwater speeds higher than 80 knots can produce decreases in daily lighterage costs at the longer (75 n. miles) distances.

Sensitivity of air wall air-cushion vehicle characteristics to variations of the nominal assumed values of several parameters was determined. The purpose of performing sensitivity analyses is to establish a level of confidence that the analytically determined vehicle characteristics and costs are not subject to significant change as a result of changes to assumed basic data values.

Air wall vehicle sensitivity investigations were limited to those vehicles required to have a 10 ton payload, 80 knot overwater speed, 15 knot land speed and mission radii of 25 n. miles over water and 5 n. miles on land.

Selection of the specified 25 n. mile water and 5 n. mile land radii is based on the following:

(1) The selected radii are consistent with the maximum operational radii currently planned and provided with existing equipment as shown in Reference 2.

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 55% INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = S[2+.67(L/S)^.5]; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 75 N.MI.; l_o/h = .35; VEHICLE WIDTH NOT LIMITED

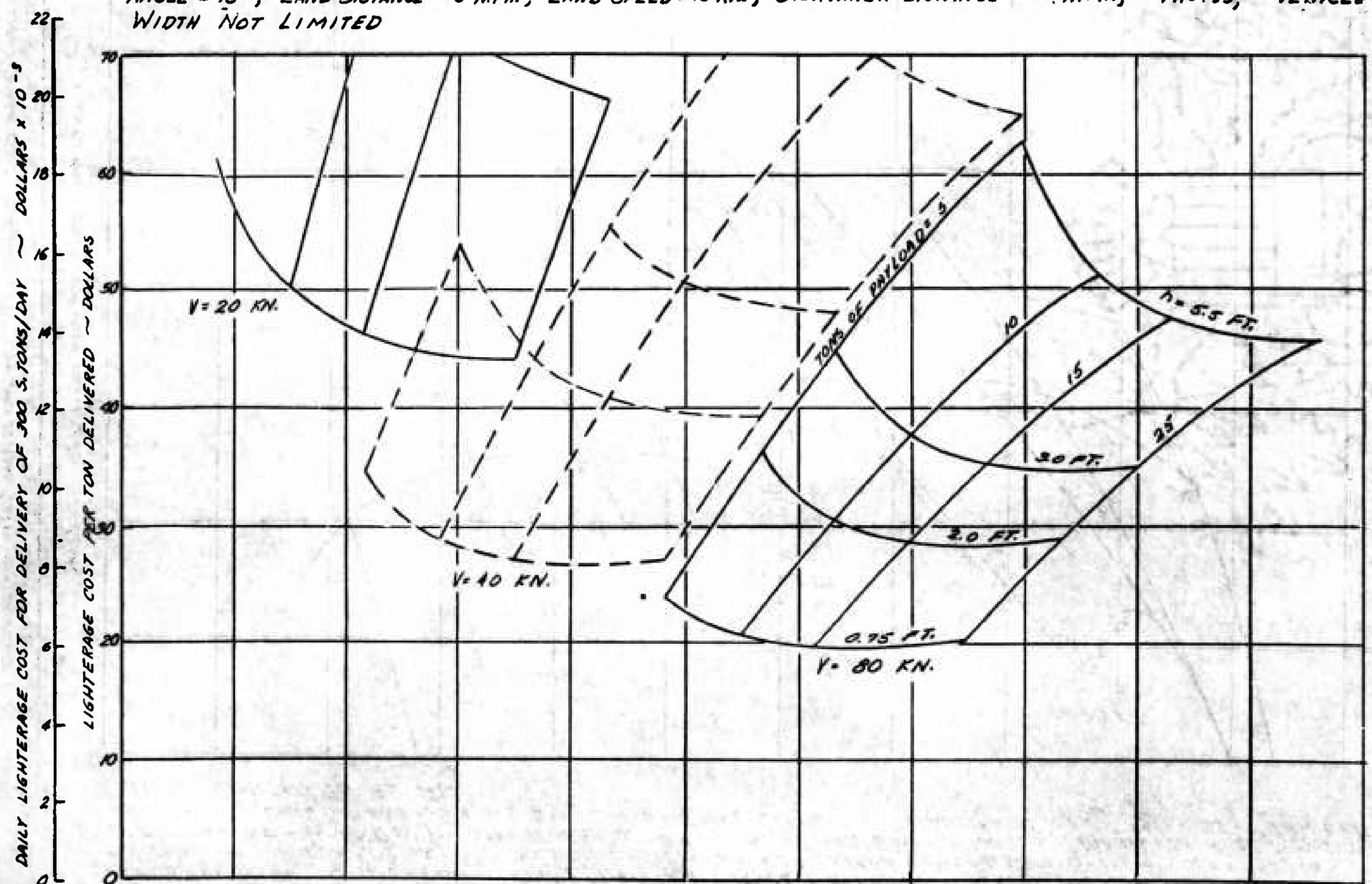


Figure V-14

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR/YR.; MAINTENANCE + ATTRITION = 55% INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = 5[2+.67(W/S)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 75 N.MI.; hc/h = .35; VEHICLE WIDTH LIMITED TO 35 FT.

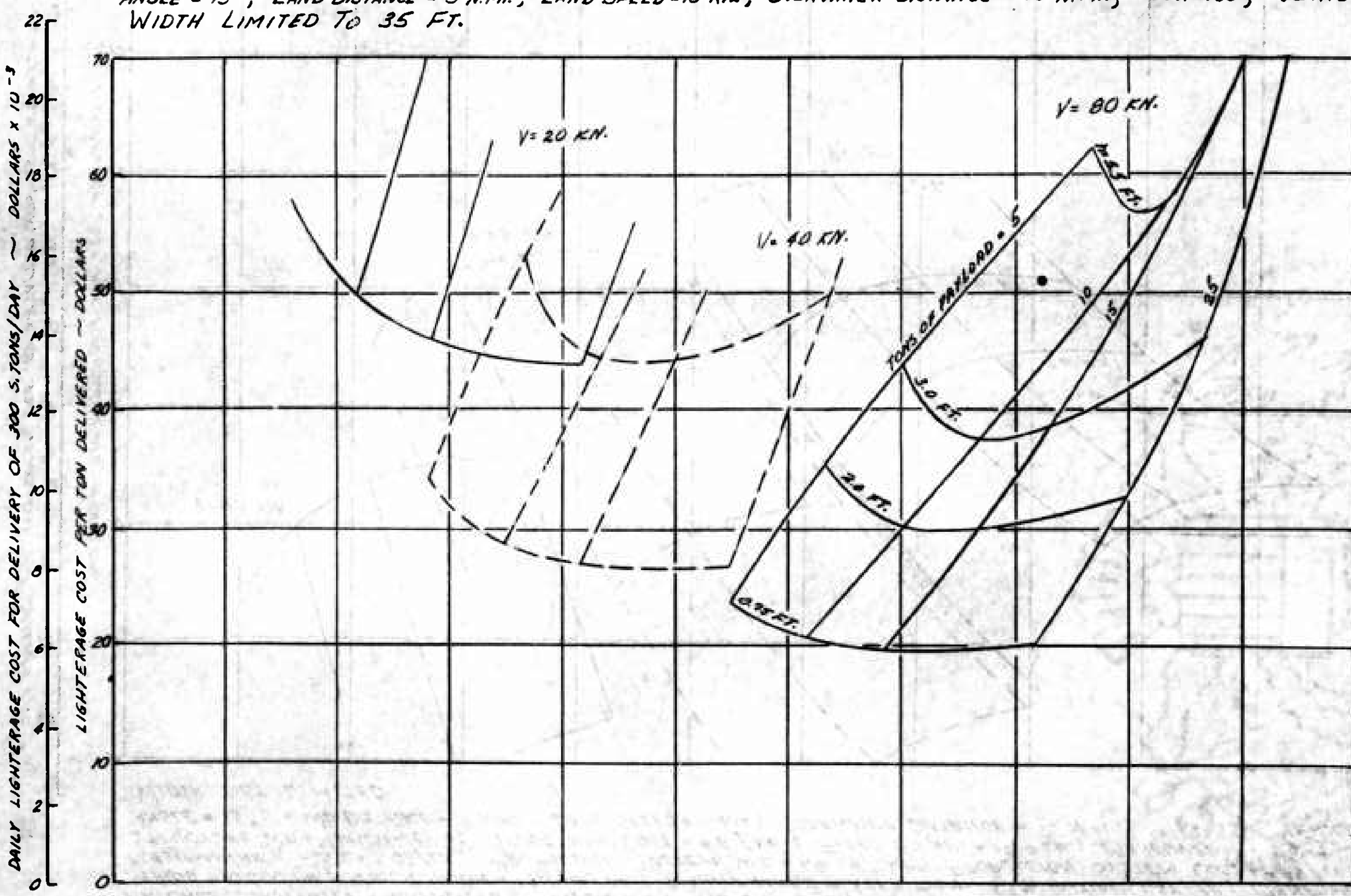


Figure V-15

Operations conducted with air cushion lighterage in the 1965 to 1970 time period will probably be made compatible with existing equipment capabilities and, therefore, the selected mission radii are deemed adequate.

(2) Shorter operational radii missions can be conducted by the same vehicles without refueling each cycle or with greater payloads and no reduction in operating height or speed.

(3) Longer operational radii missions can be conducted by the same vehicles by operating at reduced heights or reduced payload.

Additionally, the radii selected represent a significant increase in full payload range capabilities over contemporary wheeled amphibious lighterage (125 n. mile range as opposed to 24 n. mile range of the LARC-15).

a. <u>Air Wall Vehicle Characteristics</u>

The significant characteristic data for minimum daily lighterage cost air wall vehicles designed to 25 n. miles overwater distance are presented on Figures V-16 through V-18.

The gross weight and planform loading of minimum daily lighterage cost air wall vehicles are presented on Figure V-16 as a function of operating height. The installed shaft horsepower, cruise shaft horsepower and width of these vehicles are presented on Figure V-17. The difference between installed and cruise shaft horsepower shown on Figure V-17 results from the nominal .25 'g' lateral maneuver requirement at cruise speeds. The significant increase in air wall vehicle gross weight, size and installed power requirements which accompany increasing operating heights is graphically illustrated on the cited figures.

Figure V-18 presents the range-payload characteristics of selected minimum cost air wall vehicles. The variations shown are for constant speed cruise at 80 knots and reflect a decreasing cruise power from the design value at start of cruise to a lower value at mission termination. The reduction in cruise power

CHARACTERISTICS OF MINIMUM COST AIR WALL VEHICLES

PAYLOAD = 10 TONS, $V = 80$ KN, .25 'g' MANEUVER, $t_e/h = .35$, $\ell/b = 2.0$, $\theta_j = 15°$, $D_W = 25$ N. MI., $D_L = 5$ N. MI., $V_L = 15$ KN.

VEHICLES LIMITED TO 35 FT. WIDTH — — —

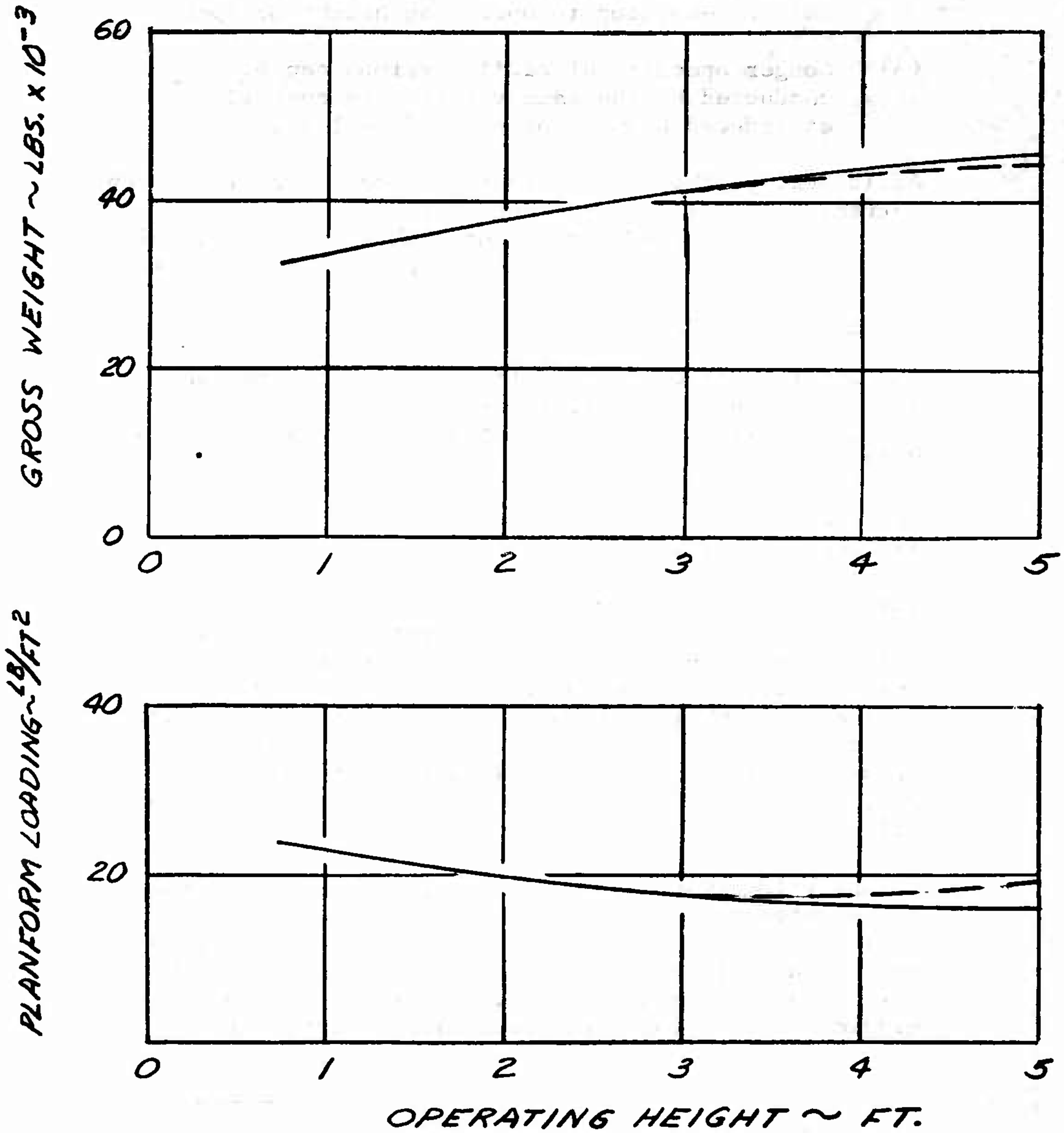


Figure V-16

CHARACTERISTICS OF MINIMUM COST AIR WALL VEHICLES

PAYLOAD = 10 TONS, $V = 80$ KN., .25 'g' MANEUVER,
$t_e/h = .35$, $\ell/b = 2.0$, $\theta_J = 15°$, $D_W = 25$ N.MI.,
$D_L = 5$ N.MI., $V_L = 15$ KN.

VEHICLES LIMITED TO 35 FT. WIDTH — — —

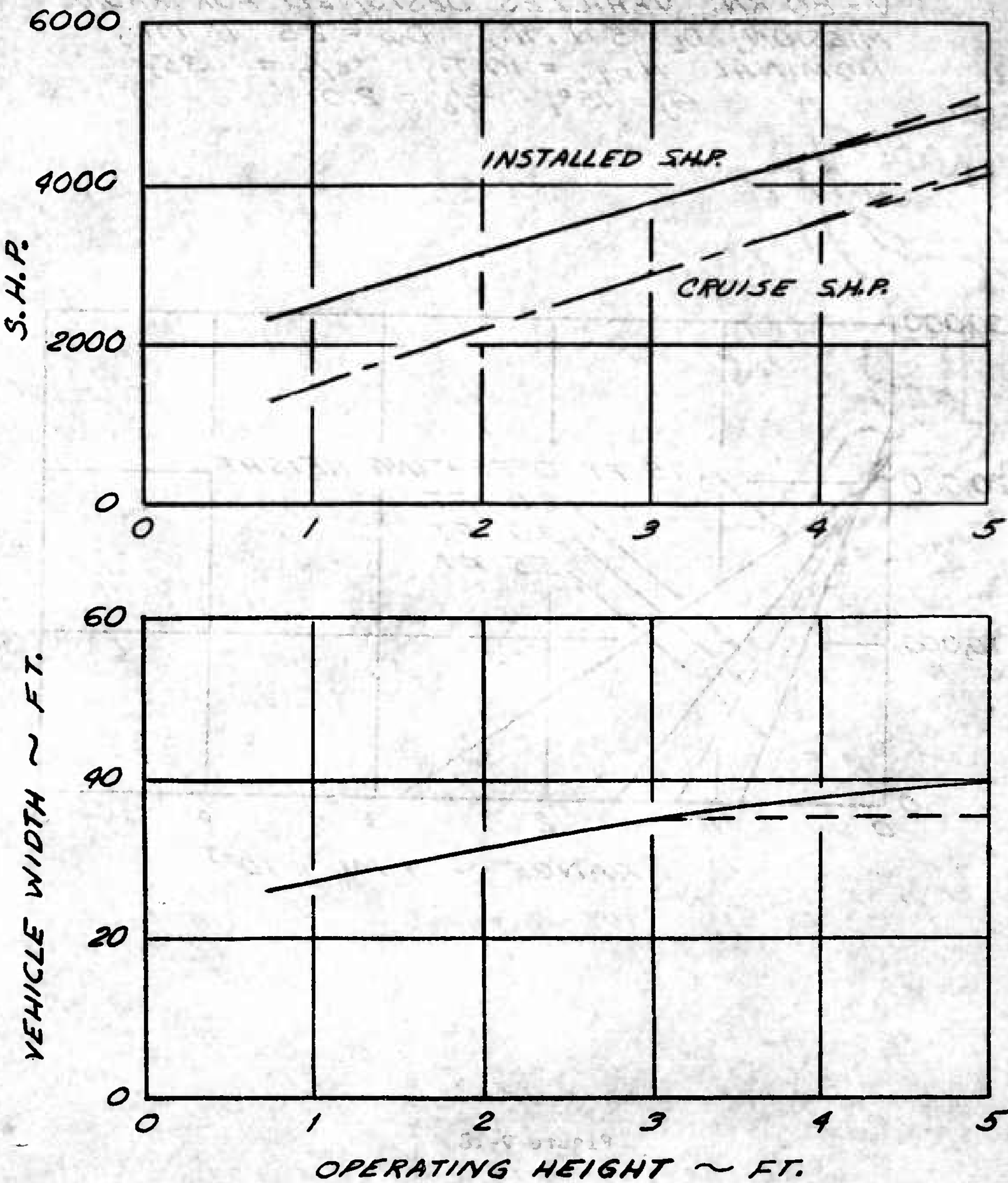


Figure V-17

MINIMUM COST AIR WALL AIR CUSHION VEHICLE PAYLOAD-RANGE RELATIONSHIPS

V = 80 KN., VEHICLES DESIGNED FOR RADIUS MISSION, D_L = 5 N. MI., D_W = 25 N. MI., NOMINAL $W_{P.L.}$ = 10 T., t_e/h = .35, $\theta_j = 15°$, ℓ/b = 2.0

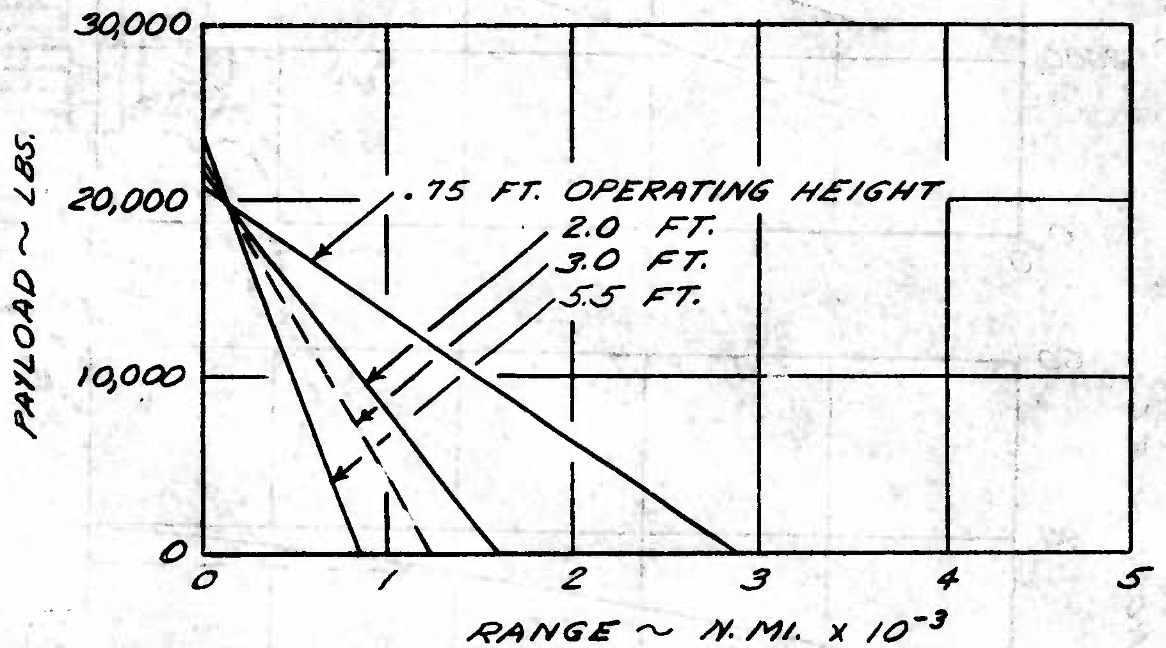


Figure V-18

with diminishing weight is not quite proportional to the three-halves power of vehicle weight due to the constant power increment required to overcome external drag. The cruise power reduction with diminishing weight is more nearly that associated with a constant weight to drag ratio vehicle.

The beneficial effects of aerodynamic lift are not included in the range-payload computations.

b. Maneuver

The required maneuver capability of air wall vehicles was varied to ascertain the sensitivity of vehicle characteristics to this parameter. Investigations with air wall vehicles (as previously indicated) were limited to those required to have 10 ton payload, 80 knot water speed ~~and mission~~ radii of 5 n. miles over land and 25 n. miles over water. The effects on air wall vehicle costs and characteristics due to varying cruise speed lateral maneuver capability from .1 'g' to .5'g' are presented on Figures V-19, V-20 and V-21.

Figure V-19 shows that a reduction of the maneuver requirement from .25 'g' to .1 'g' (60 percent) results in an approximately uniform incremental lighterage cost decrease of three dollars per ton delivered (approximately 15%). An increase of maneuver requirement to .5 'g' (twice the nominal value) results in increasingly greater incremental cost increases with higher operating heights. The lighterage costs are shown to increase approximately 40 percent for a 100 percent increase in maneuver capability.

Figure V-20 presents the gross weight variation of minimum cost air wall vehicles with variations of design maneuver capability. A gross weight reduction of approximately 6.5 percent results from a maneuver capability reduction to .1 'g'. A gross weight increase approximating 12.5 percent results from an increase in maneuver capability from .25 'g' to .5 'g'.

The variation of installed and cruise shaft horsepower requirements with maneuver capability requirements are shown on Figure V-21, which graphically illustrates the installed power penalties associated with increasing

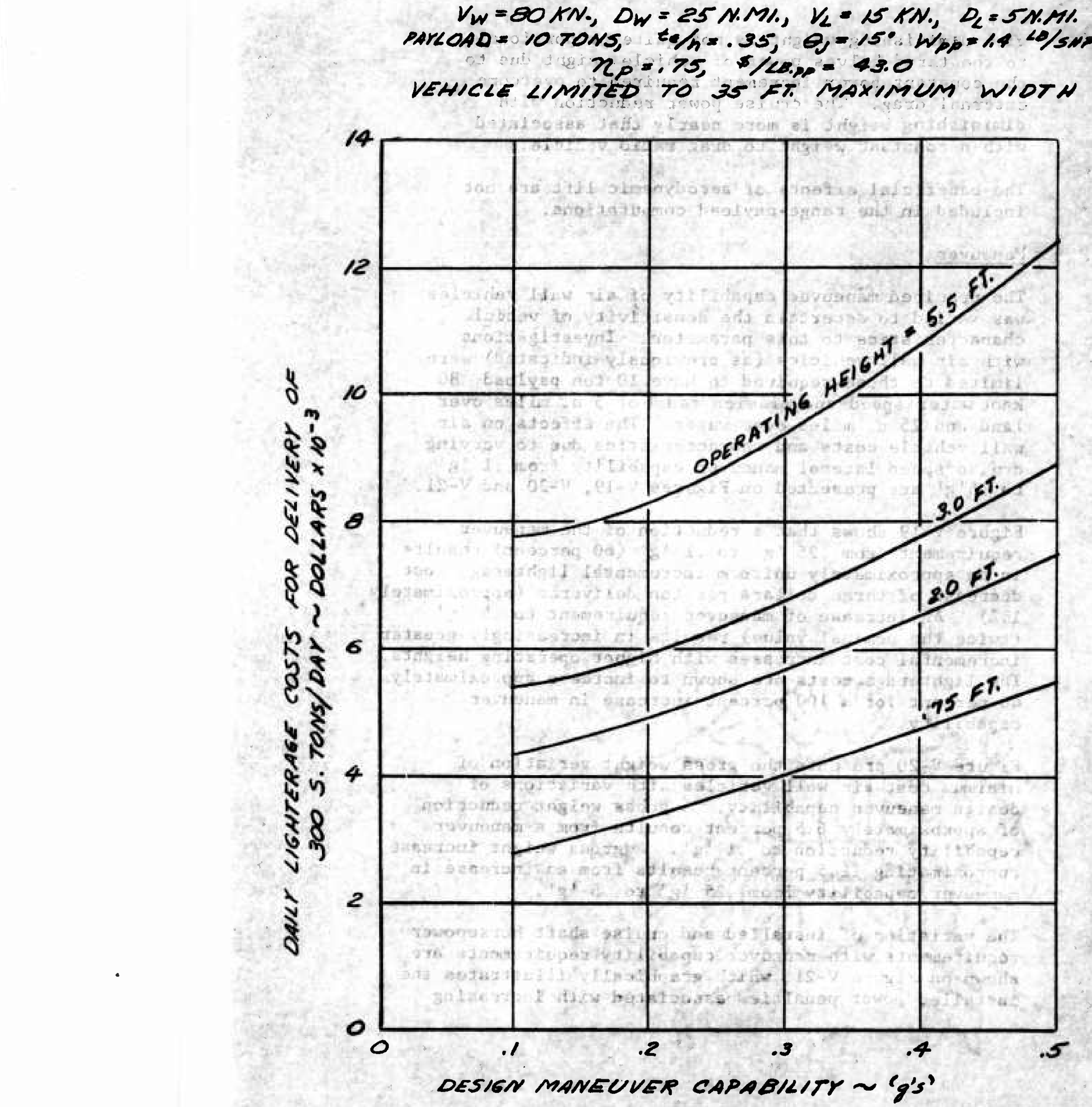


Figure V-19. Effect of Maneuver Criteria on Air Wall Air Cushion Lighterage Costs.

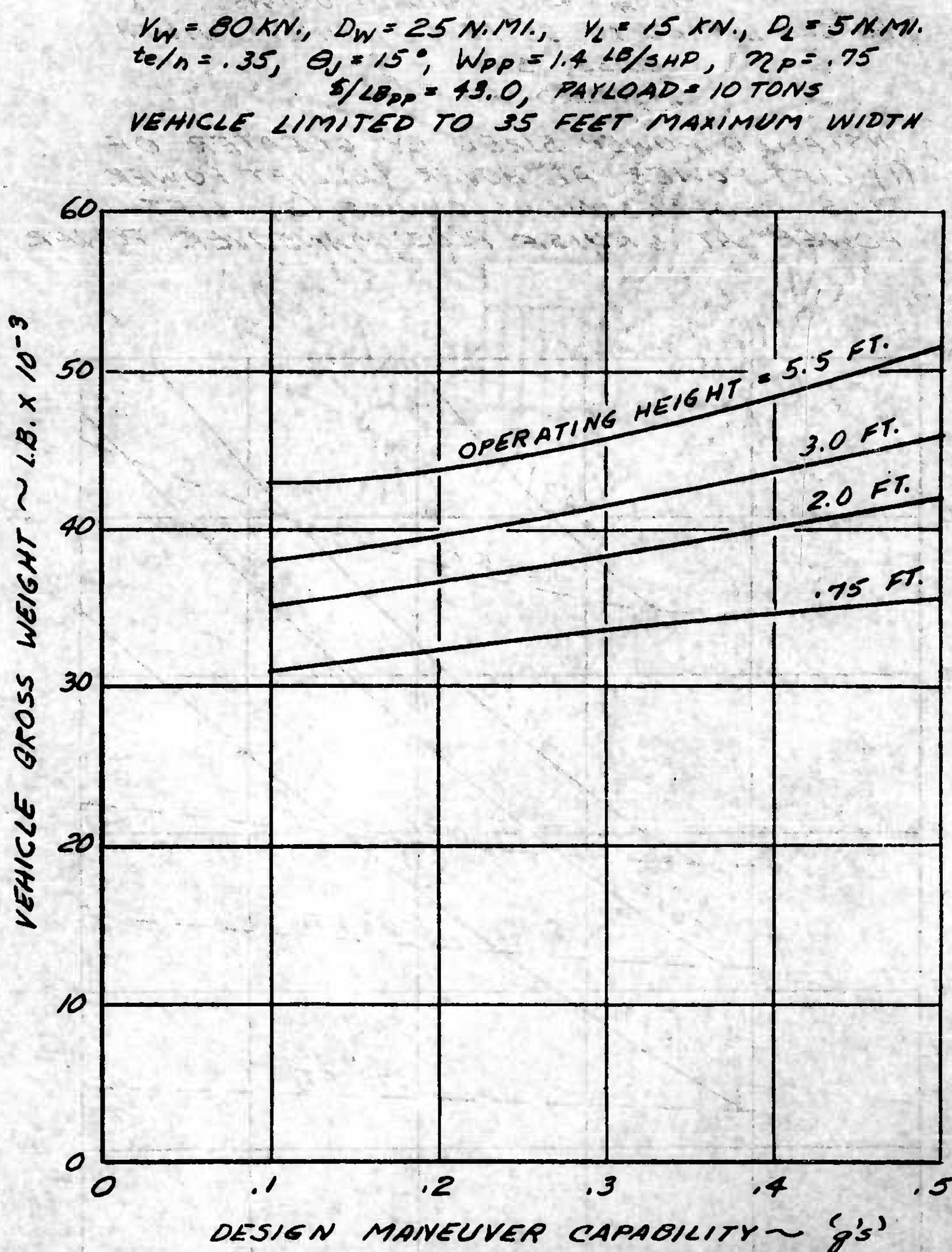


Figure V-20. Effect of Maneuver Criteria on Air Wall Air Cushion Lighterage Weight.

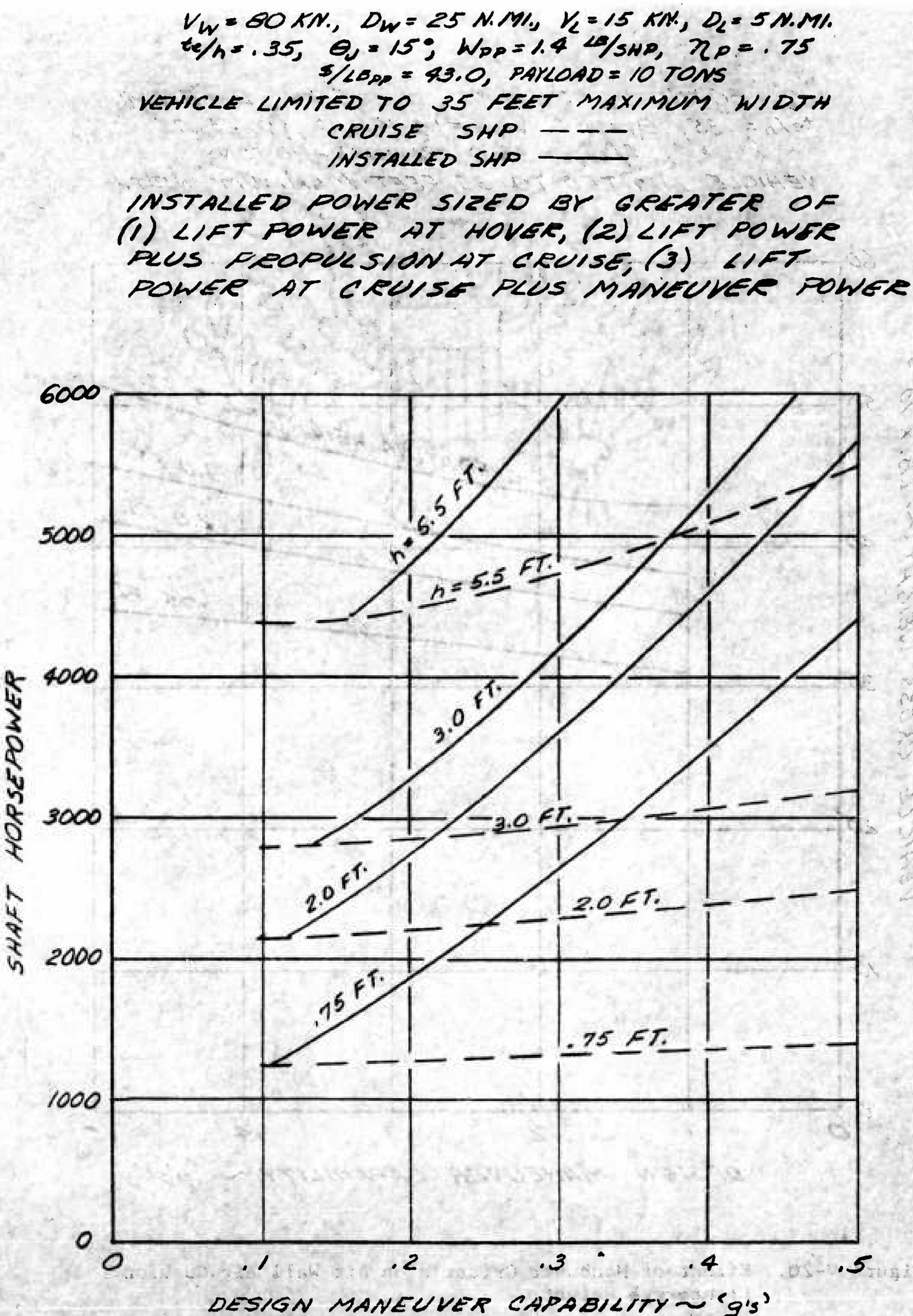


Figure V-21. Effect of Maneuver Criteria on Air Wall Air Cushion Lighterage Power.

maneuver requirements.* The cited figure shows that maneuver requiremens approximating .1 'g' at low operating heights and .15 'g' at higher operating heights can be achieved with powerplants sized to satisfy the cruise power requirements. Maneuver capability requirements in excess of .1 'g' to .15 'g' therefore cause larger powerplants to be installed in the vehicle and cause the increased vehicle costs and weights.

c. <u>Propulsion</u>

Variations to propulsion system cost, weight and propulsive efficiency were investigated to determine air wall vehicle sensitivity to these parameters.

Figure V-22 presents the inter-related effects of propulsion system cost and weight with no changes to the parameters of propulsion system component efficiencies. A 16 percent change in propulsion system costs ($7/lb) above and below the nominal ($43/lb) value results in approximately an 8 percent change in lighterage daily costs at a propulsion system weight of 1.4 pounds per shaft horsepower. The same 16 percent variation to propulsion system cost results in approximately a 10 percent change in lighterage daily costs at a propulsion system weight of 2.0 pounds per shaft horsepower.

A 43 percent increase in the propulsion system weight (.6 pounds per shaft horsepower) from 1.4 to 2.0 pounds per shaft horsepower increases the daily lighterage costs approximately 31 percent. The air wall type vehicle, therefore, indicates approximately a 50 percent sensitivity to propulsion system costs and a 75 percent sensitivity to propulsion system weight. (That is,a 1 percent change in propulsion system costs results in a one-half percent change in daily lighterage costs and a 1 percent change in propulsion system weight results in a three-quarter percent change in daily lighterage costs.)

It is concluded on the basis of the foregoing that, opportunity permitting, greater effort (on the ratio of 1.5 to 1) should be made to reduce the air wall vehicles propulsion system weight than its cost. For example, if the opportunity exists to decrease propulsion system weight by 1 percent at an increase in propulsion system cost of 1 percent, a net daily lighterage cost savings of

*Installed power is sized by the greater of (1) lift power at hover, (2) lift power plus propulsion at cruise or (3) lift power at cruise plus maneuver power.

AIR WALL AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 56 % INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = VAR. LB./SHP; PROPULSION SYSTEM COST = \$ VAR./LB.; STRUCTURE WT. = $S[2+.67(\ell/s)^{.5}]$; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 0°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; OVERWATER SPEED = 80 KN.; t_e/h_s = .35; VEHICLE LIMITED TO 35 FT.; PAYLOAD = 10 TONS

EFFECT OF PROPULSION SYSTEM COST AND WEIGHT

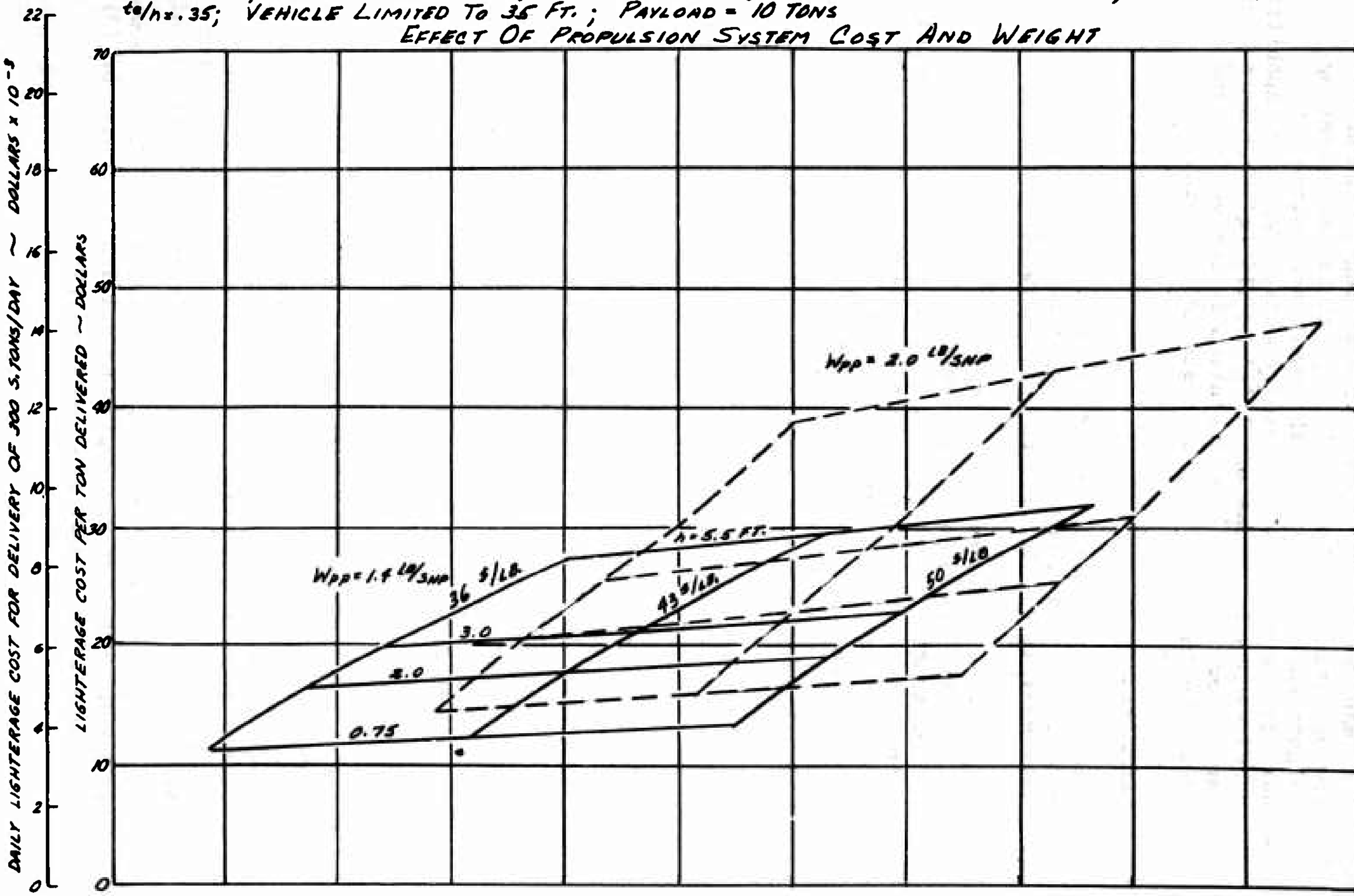


Figure V-22

one-fourth percent will result if all other factors remain unchanged. Caution must be excercised in applying this sensitivity data, since the trade-off relationships are only applicable over a small range of values (approximately the range investigated).

The effect of changes to the propulsive (thrusting) efficienty (η_p) of the air wall vehicle's propulsion system were also investigated. These changes can be interpreted as a change in vehicle drag, since drag and propulsive efficiency are directly related in the equation for thrust shaft horsepower required.

$$\text{Thrust } SHP_{Req.} = \frac{D}{\eta_p} \cdot \frac{V_{kn}}{326}$$

The effects of a 50 percent propulsive efficiency on vehicle characteristics are shown on Figures V-23, V-24 and V-25. Figure V-23 shows propulsive efficiency effects on daily lighterage costs. The one-third reduction in propulsive efficiency (equivalent to a 33 1/3 percent increase in combined momentum and external drags) results in a daily lighterage cost increase approximating 10 percent.

The increased cruise fuel consumption resulting from decreased propulsive efficiency causes an increase in vehicle gross weight approximating 2 percent, as shown on Figure V-24. However, the planform loading of minimum lighterage cost air wall vehicles are also shown to increase and no noticeable vehicle size changes occur when compared to vehicles with a propulsive efficiency of 75 percent.

The installed power requirements of the minimum lighterage cost air wall vehicles, shown on Figure V-25, increase approximately 2 percent, (the same as the gross weight change). The cruise power requirements reflect the most significant change due to the 33 1/3 percent decrease in propulsive efficiency; - showing an increase of approximately 24 percent in comparison to vehicles with a propulsive efficiency of 75 percent.

It is concluded from the foregoing that the configuration of minimum lighterage cost air wall air cushion vehicles designed to ranges on the order of 150 n. miles is virtually unaffected by propulsive efficiency or drag variations approximating 30 to 40 percent. The significant effects

EFFECT OF PROPULSIVE EFFICIENCY ON AIR WALL AIR CUSHION VEHICLE LIGHTERAGE COST

PAYLOAD = 10 TONS, D_W = 25 N.MI., V = 80 KN.,
D_L = 5 N.MI., V_L = 15 KN., θ_j = 15°, t_e/h = 0.35,
.25 'g' MANEUVER.

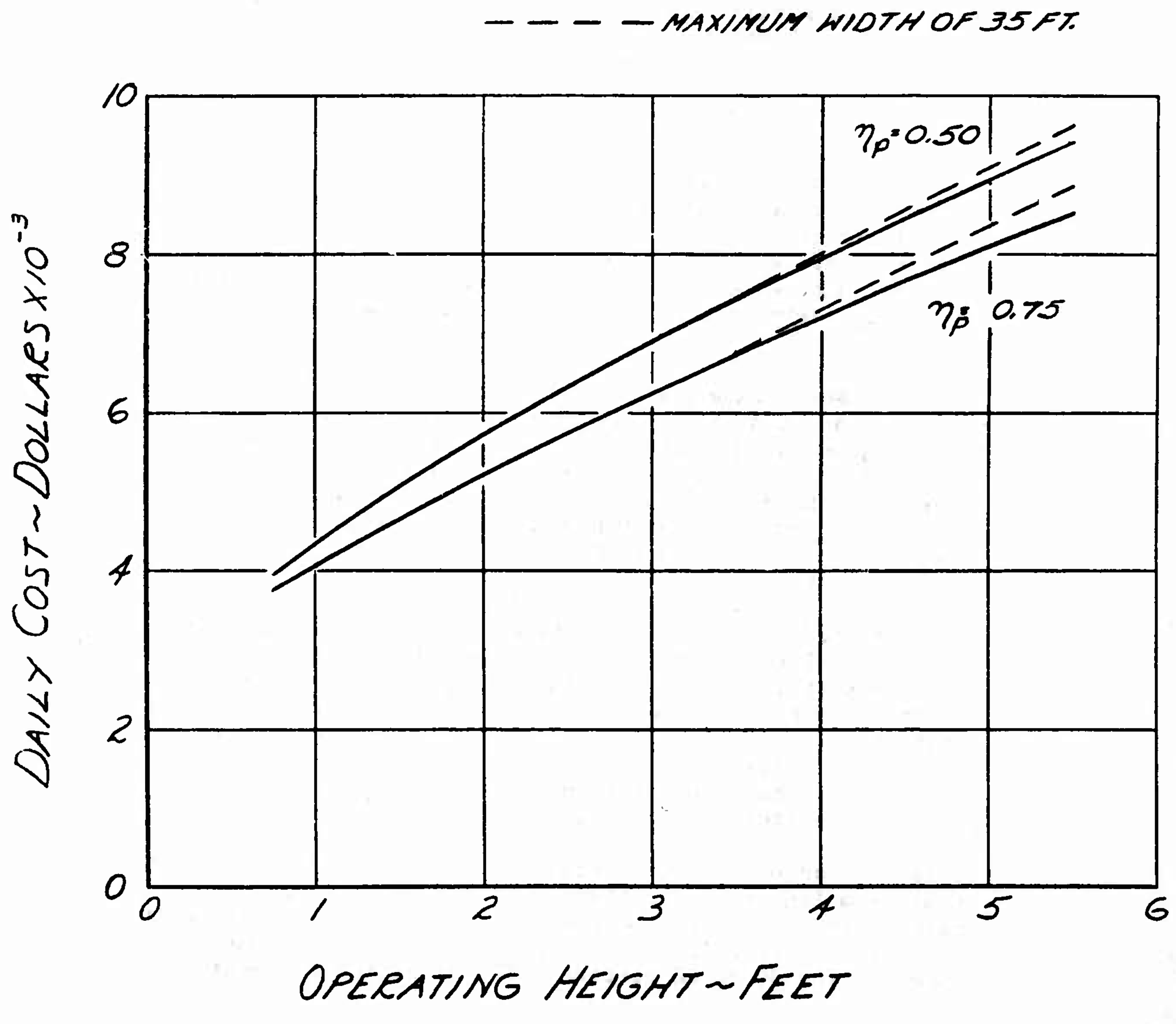


Figure V-23

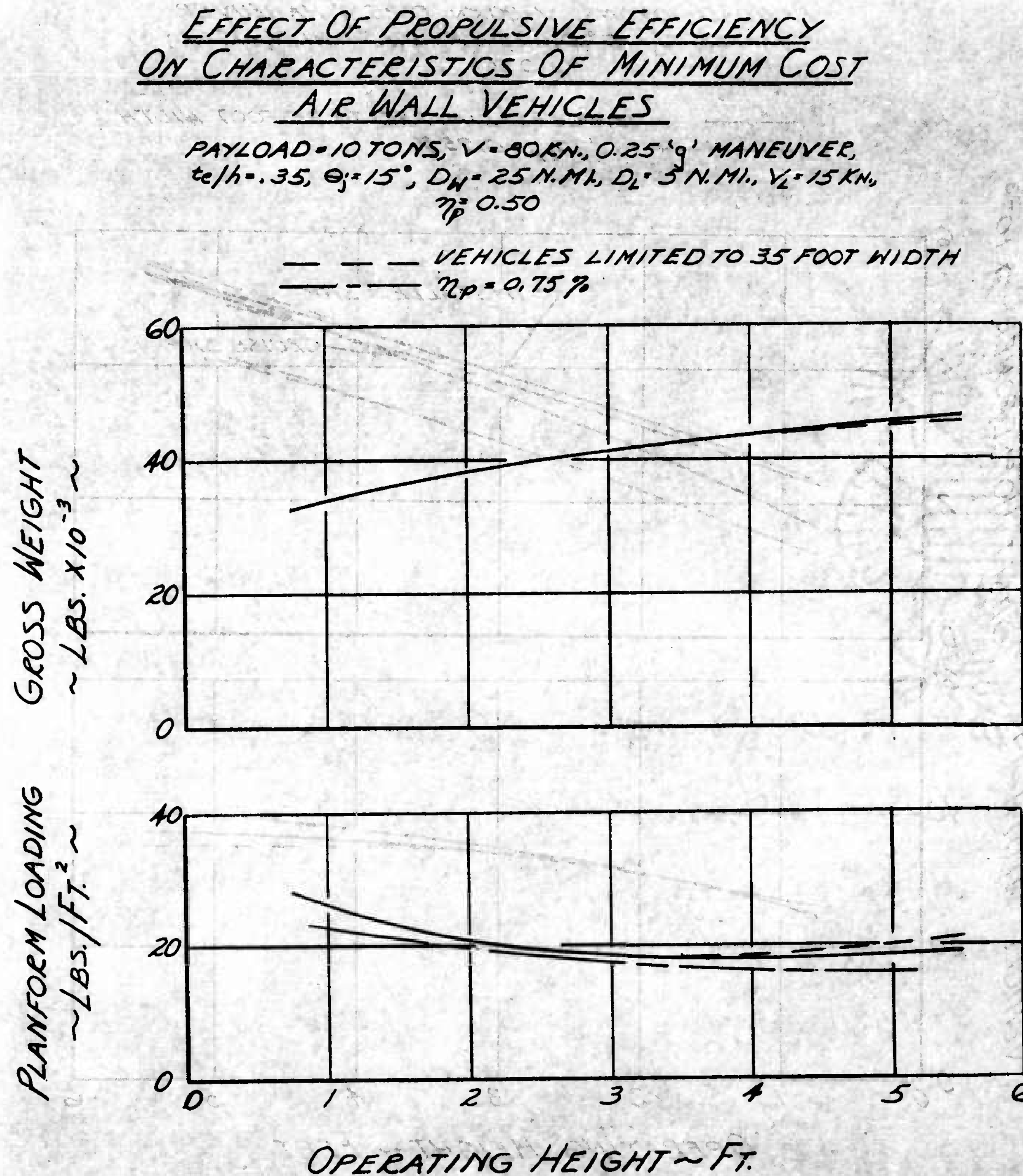

EFFECT OF PROPULSIVE EFFICIENCY
ON CHARACTERISTICS OF MINIMUM COST
AIR WALL VEHICLES
PAYLOAD = 10 TONS, V = 80 KN., 0.25 'g' MANEUVER,
te/h = .35, θj = 15°, DW = 25 N.MI., DL = 3 N.MI., VL = 15 KN.,
ηp = 0.50
VEHICLES LIMITED TO 35 FOOT WIDTH
ηp = 0.75 %
GROSS WEIGHT ~ LBS. X 10^-3 ~
PLANFORM LOADING ~ LBS./FT.² ~
OPERATING HEIGHT ~ FT.
0
20
40
60
0
20
40
0
1
2
3
4
5
6

Figure V-24

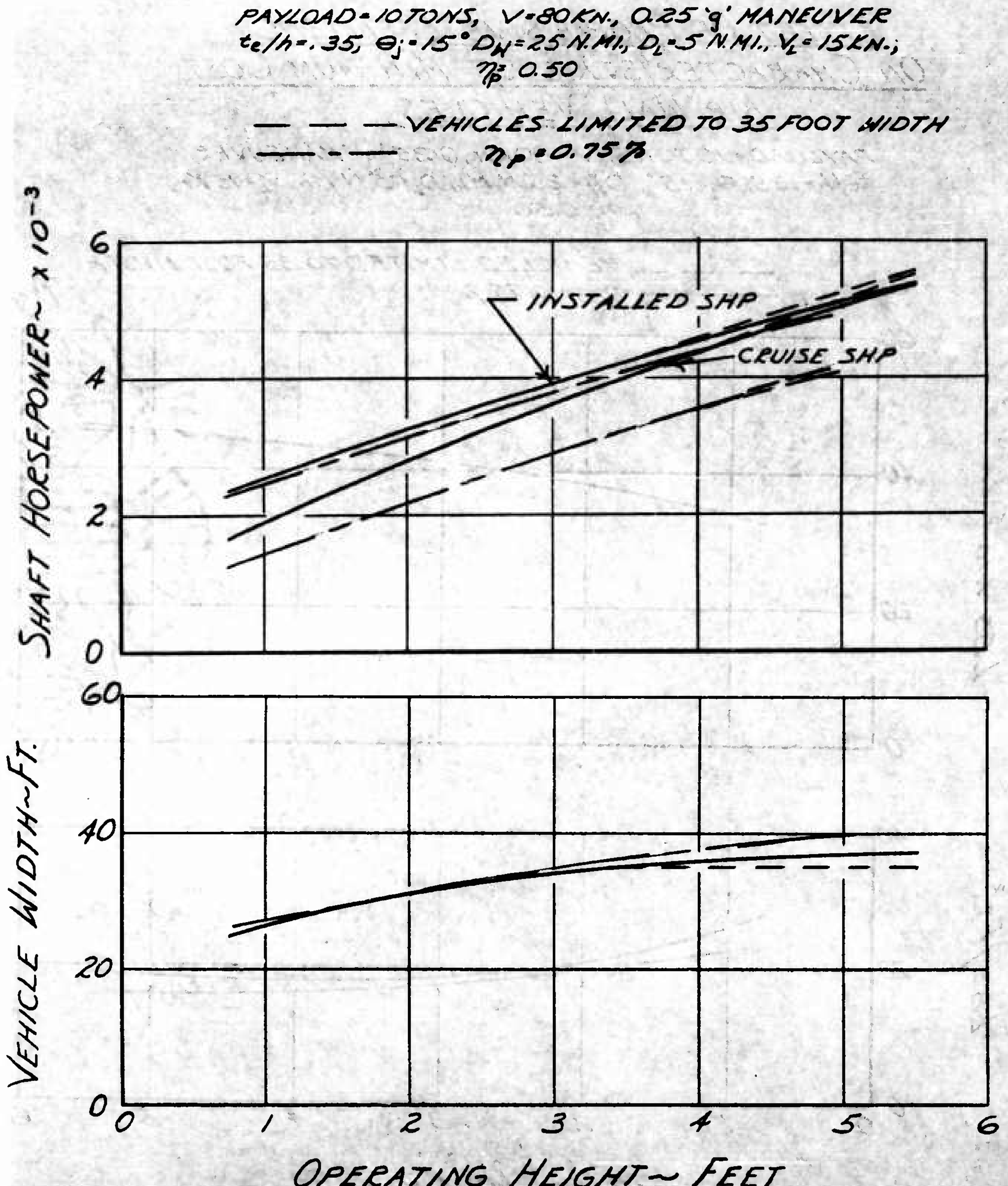


Figure V-25. Effect of Propulsive Efficiency on Characteristics of Minimum Cost Air Wall Vehicles.

of propulsive efficiency variations are in terms of fuel consumption which relate to lighterage costs at a sensitivity approximating 30 percent (i.e. a 1 percent change in propulsive efficiency reflects a three-tenths percent change in lighterage costs).

d. Structure

Variations to air wall vehicle unit structure cost and weight show that the minimum lighterage cost air wall vehicle is appreciably more sensitive to unit structure weight than to unit structure costs.

Figure V-26 presents the daily lighterage costs of air wall air cushion vehicles having unit structure costs of six dollars per pound ($6/lb) and fifteen dollars per pound ($15/lb). The effects on daily lighterage costs of increasing the structure weight by 50 percent above the nominal values are also shown on Figure V-26. The structure weight sensitivity of the air wall air-cushion vehicle increases markedly with increasing design operating height. At the lowest height (.75 feet), the 50 percent unit structure weight increase causes a 16.5 percent increase in lighterage costs, while at the highest operating height investigated (5.5 feet) a 35 percent increase in lighterage cost results. The sensitivity of the air wall vehicles lighterage costs to unit structure weight at design height of 3.0 feet approximates a ratio of 1 to 2. (i.e. a 1 percent increase in structure weight results in a one-half percent increase in lighterage costs.)

Structural unit costs are shown to exert less influence on lighterage costs as design operating height is increased. The sensitivity of lighterage costs to structure unit costs at a design height of 3.0 feet approximates a ratio of 1 to 7 when the nominal unit structure weights are assumed. (i.e. a 1 percent increase in unit structure costs results in only one-seventh percent increase in lighterage costs.) The lighterage cost sensitivity at a design operating height of 5.0 feet approximates a ratio of 1 to 6 when unit structure weights 50 percent greater than the nominal values are assumed.

Figure V-27 presents the air wall vehicle planform loading and gross weight characteristics when unit

structure costs are varied and the nominal unit structure weights are assumed. At the lower design operating heights, the higher (fifteen dollars per pound) unit structure costs result in small decreases in vehicle gross weight but rather significant increases in vehicle planform loadings.

Figure V-28 presents the air wall vehicle characteristics when unit structure costs are varied and unit structure weights 50 percent larger than the nominal values are assumed. The higher (fifteen dollars per pound) unit structure costs again result in small vehicle gross weight changes and significant increases in vehicle planform loadings at the lower design operating heights.

Comparison of data presented on Figures V-27 and V-28 reveals that the 50 percent increase in unit structure weight results in a 21 percent increase in vehicle gross weight, indicating a sensitivity ratio of approximately 1 to 2.5. Fortunately, as shown by the data on Figure V-29, size of the minimum lighterage cost air wall vehicle is only slightly affected by the variation of unit structure weight. The air wall vehicle designed to an operating height of two feet have widths of 31.5 feet when the unit structure cost is six dollars ($6.00) per pound and 29.5 feet when the unit structure cost is fifteen dollars ($15.00) per pound, and are independent of assumed unit structure weight. Therefore, variations of unit structure costs results in negligibly small changes in the size of air wall vehicles for minimum lighterage costs (sensitivity ratio of 1 to 24).

The foregoing data leads to the conclusion that the air wall vehicle lighterage costs are primarily affected by variations in unit structure weights, being almost 3.5 times as sensitive to an increase in unit structure weight than unit structure cost. Fortunately, however, the assumptions of structure weight and cost do not affect the appropriate vehicle size to obtain minimum lighterage costs. An analytic vehicle optimization procedure can, therefore, be utilized to determine the appropriate vehicle size with a large measure of confidence that errors in assumptions to unit structure weights and costs will not cause significant size changes. It must be recognized, however, that any such erroneous assumptions will cause

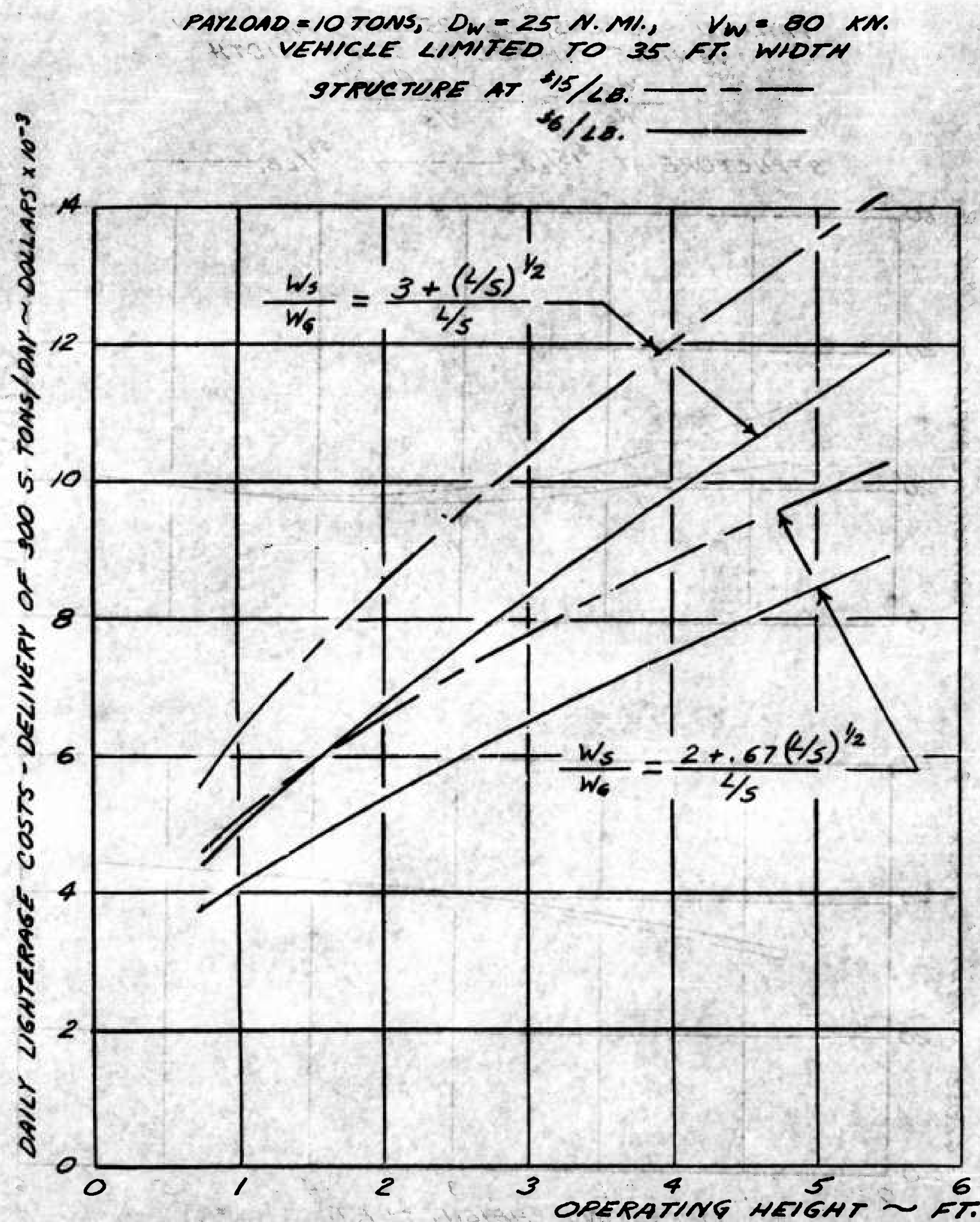


Figure V-26. Effect of Structure Weight and Cost on Air Wall Air Cushion Lighterage Vehicle Daily Costs.

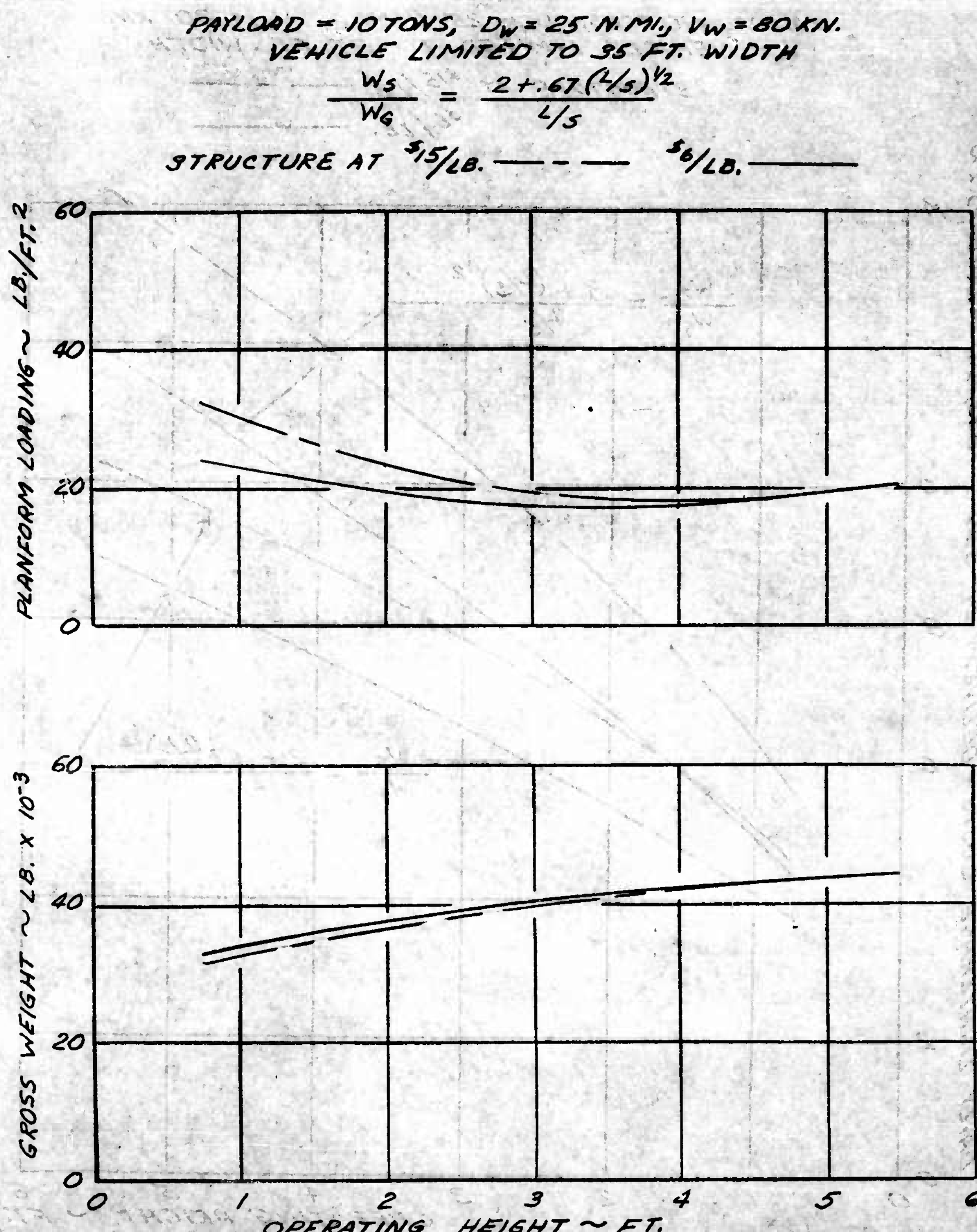


Figure V-27. Effect of Structure Weight and Cost on Air Wall Air Cushion Lighterage Vehicle Characteristics.

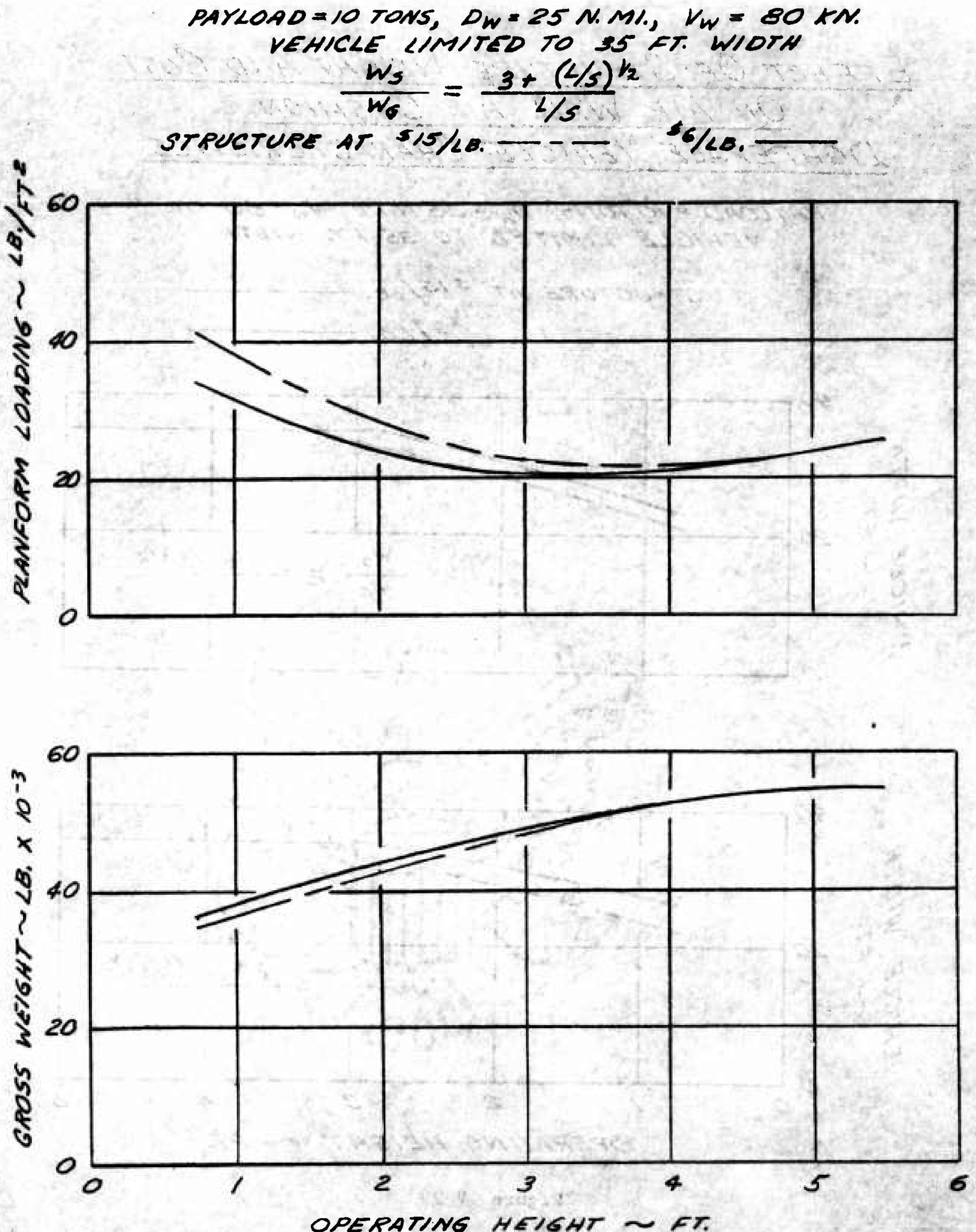


Figure V-28. Effect of Structure Weight and Cost on Air Wall Air Cushion Lighterage Vehicle Characteristics.

EFFECT OF STRUCTURE WEIGHT AND COST ON AIR WALL AIR CUSHION LIGHTERAGE VEHICLE CHARACTERISTICS

PAYLOAD = 10 TONS, D_W = 25 N.MI., V_W = 80 KN.
VEHICLE LIMITED TO 35 FT. WIDTH

STRUCTURE AT \$15/LB. — — —
\$6/LB. ————

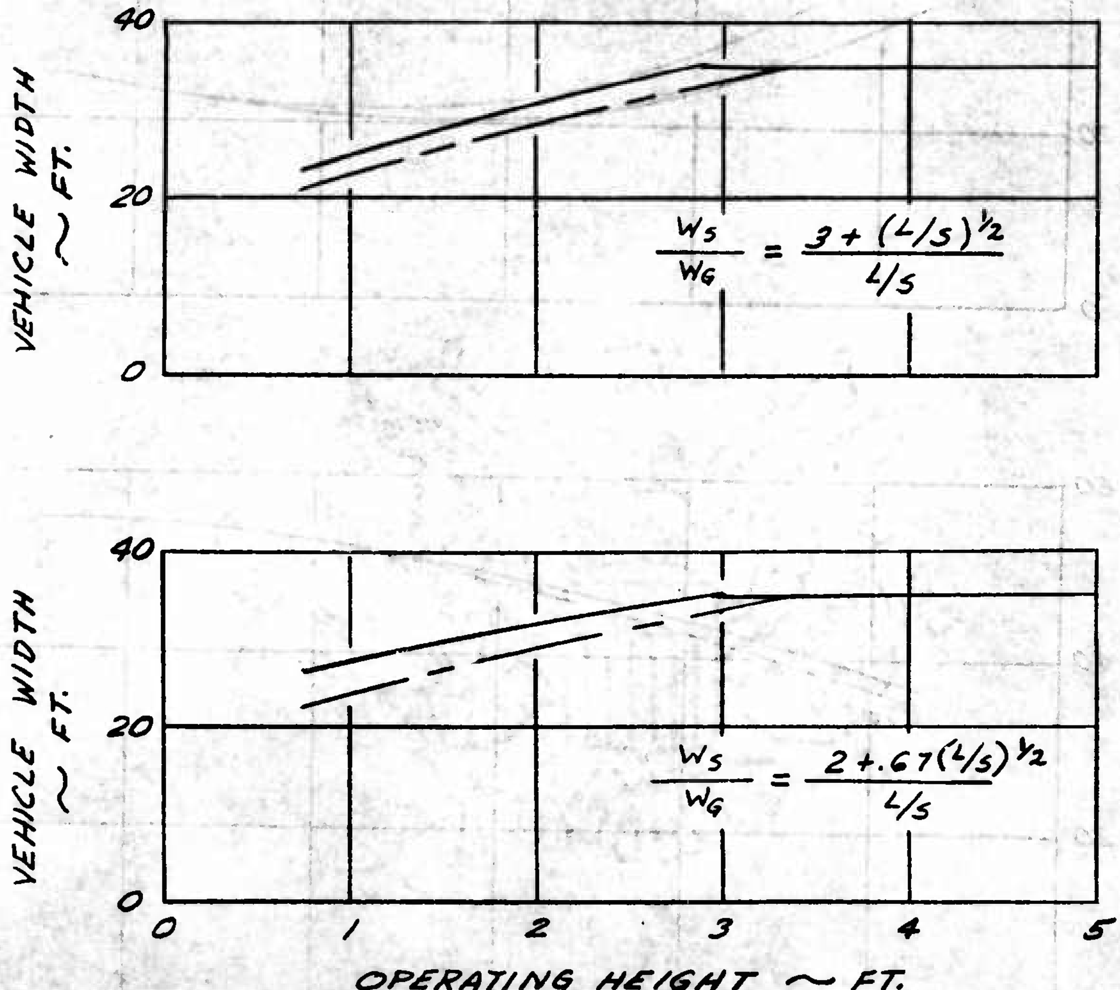


Figure V-29

changes in vehicle gross weight, propulsion system size and vehicle costs. Additionally, the foregoing comments are only applicable to vehicles designed to operating speeds, payloads and ranges not far removed from the design objectives of vehicles being discussed.

e. Maintenance Costs

As previously indicated in Section VI of this report and earlier in Section V, estimates of maintenance costs for air cushion vehicles employed in LOTS operations are "best guesses" based on projections of poorly documented figures for comparable vehicles. The lack of ACV operational data and firm design data preclude all but the most rudimentary estimates of maintenance costs. It is desirable, therefore, to examine the sensitivity of air wall vehicle designs and lighterage costs to the assumed maintenance cost values chosen.

Figures V-30 and V-31 depict the effect of varying the maintenance cost assumptions on daily lighterage costs and vehicle characteristics of air wall air cushion vehicles.

Variation of maintenance costs by plus or minus 40 percent from the assumed nominal value of 50 percent of initial cost per year results in a daily lighterage cost variations approximating 14 percent. The lighterage costs are, therefore, sensitive to vehicle maintenance costs on the ratio of 1 to 2.8 (i.e. a 1 percent change in maintenance cost results in a .35 percent change in lighterage costs).

Assumptions of maintenance cost are shown on Figures V-30 and V-31 to produce no changes in the characteristics of minimum lighterage cost air wall vehicle, except at a design height of .75 feet. An analytic procedure for determining the characteristics of minimum lighterage cost air wall vehicles can therefore be used with a high degree of confidence that assumptions of maintenance cost will not noticeably affect the results.

f. Planform Loading

The effect of planform loading variation on air wall vehicle costs and characteristics are shown on Figures V-32, V-33 and V-34 for design requirements of

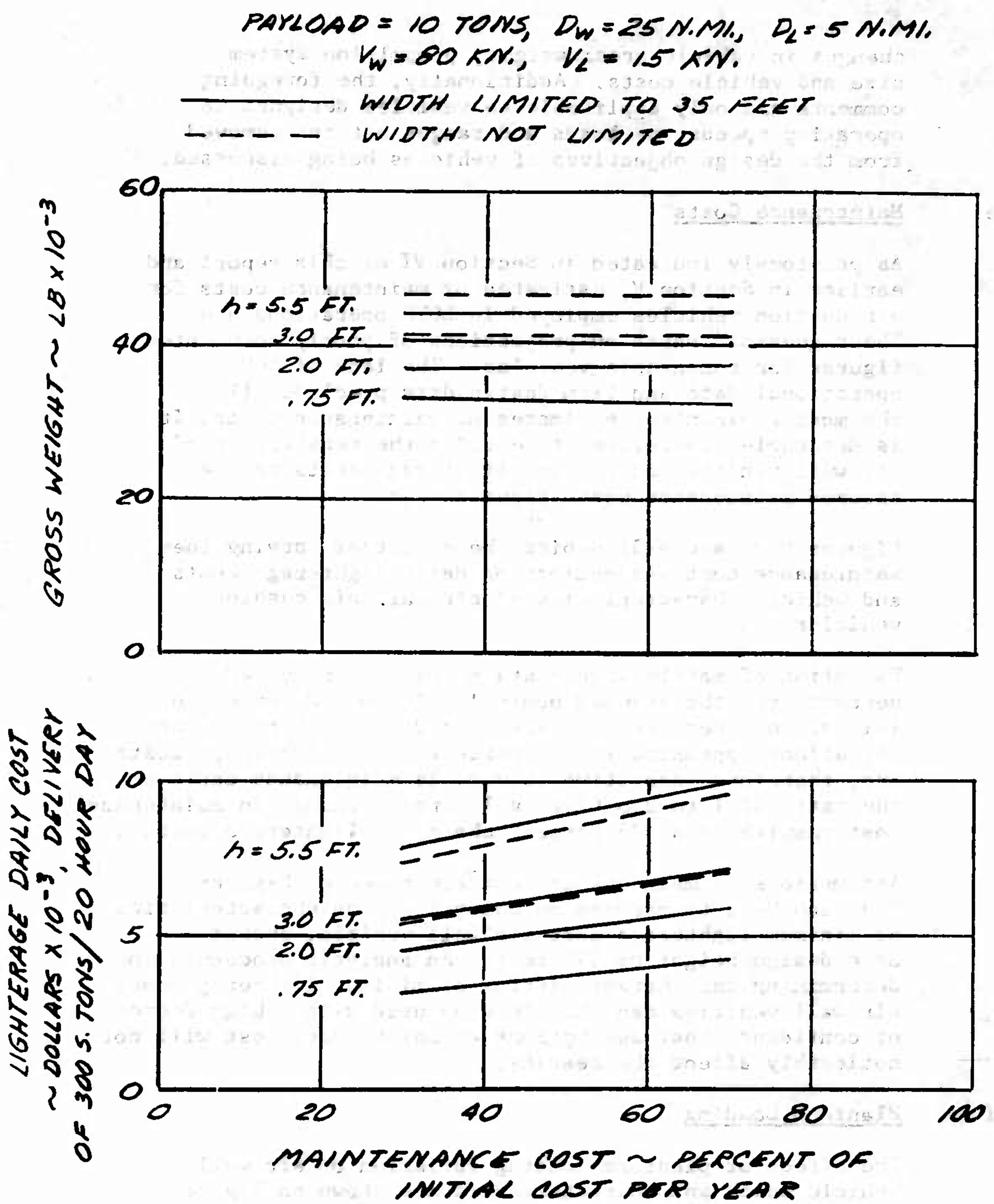


Figure V-30. Effect of Maintenance Cost on Minimum Cost Air Wall Air Cushion Vehicle Characteristics.

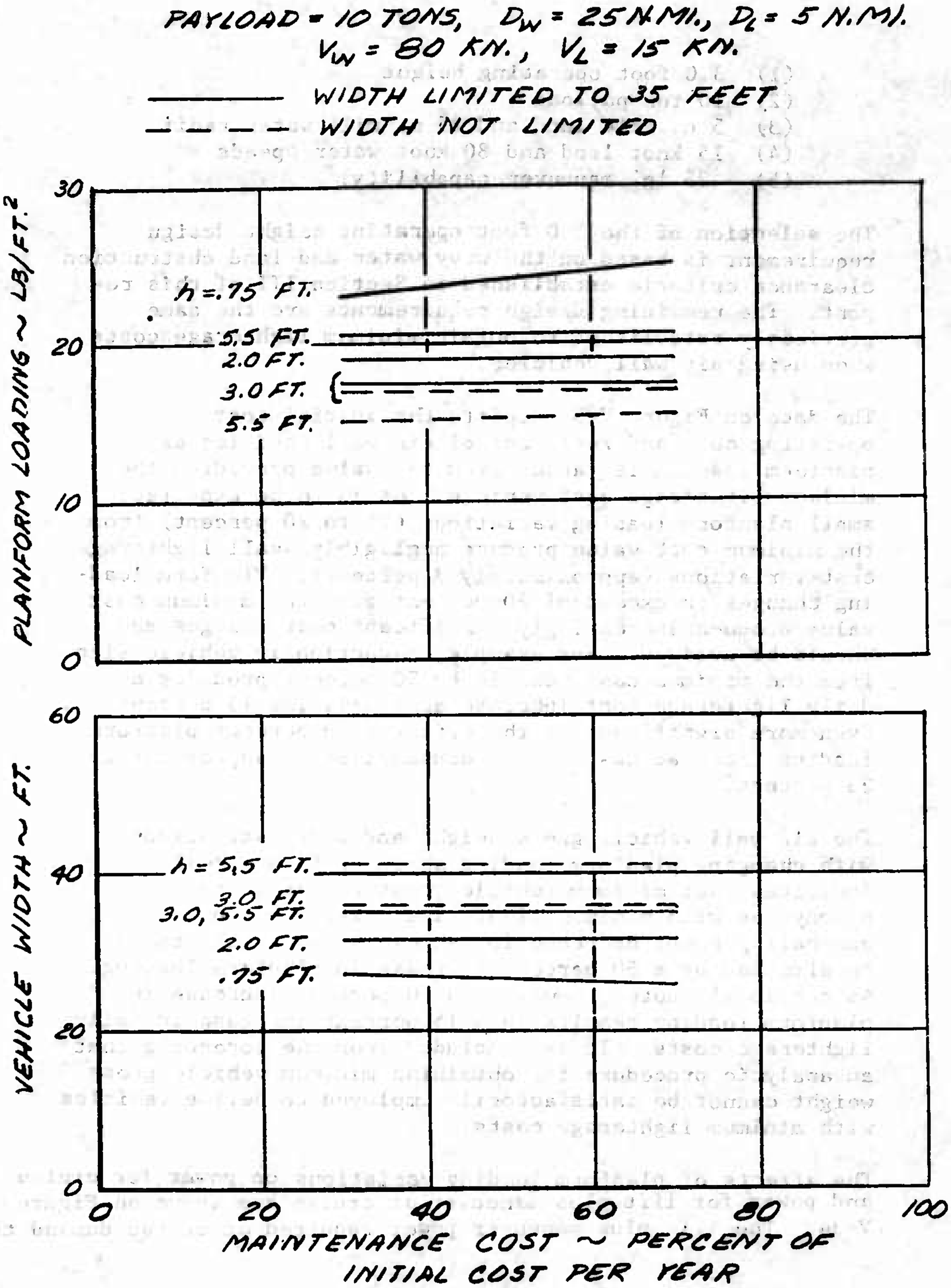


Figure V-31. Effect of Maintenance Cost on Minimum Cost Air Wall Air Cushion Vehicle Characteristics.

(1) 3.0 foot operating height
(2) 10 ton payload
(3) 5 n. mile land and 25 n. mile water radii
(4) 15 knot land and 80 knot water speeds
(5) .25 'g' maneuver capability.

The selection of the 3.0 foot operating height design requirement is based on the wavy water and land obstruction clearance criteria established in Section III of this report. The remaining design requirements are the same previously established to obtain minimum lighterage costs when using air wall vehicles.

The data on Figure V-32 depicts the initial cost, operating cost and fuel cost of air wall vehicles as planform loading is varied from the value providing the minimum lighterage cost vehicle. As is to be expected, small planform loading variations (15 to 20 percent) from the minimum cost value produce negligibly small lighterage cost variations (approximately 3 percent). Planform loading changes in excess of 20 percent from the minimum cost value produce increasingly significant cost changes and should be avoided. For example, reduction in vehicle size from the minimum cost vehicle by 50 percent produces a daily lighterage cost increase approximating 15 percent. Even more significant is the effect a 50 percent planform loading increase has on fuel consumption -- approximately 23 percent.

The air wall vehicle gross weight and width variations with changing planform loading shown on Figure V-33 indicates that minimum vehicle gross weight is not synonymous with minimum lighterage costs. A two and one-half percent decrease in vehicle gross weight could be effected by a 50 percent increase in planform loading. As previously noted, however, a 50 percent increase in planform loading results in a 15 percent increase in daily lighterage costs. It is concluded from the foregoing that an analytic procedure for obtaining minimum vehicle gross weight cannot be satisfactorily employed to define vehicles with minimum lighterage costs.

The effects of planform loading variations on power for cruise and power for lift plus maneuver at cruise are shown on Figure V-34. The lift plus maneuver power required at cruise demand the

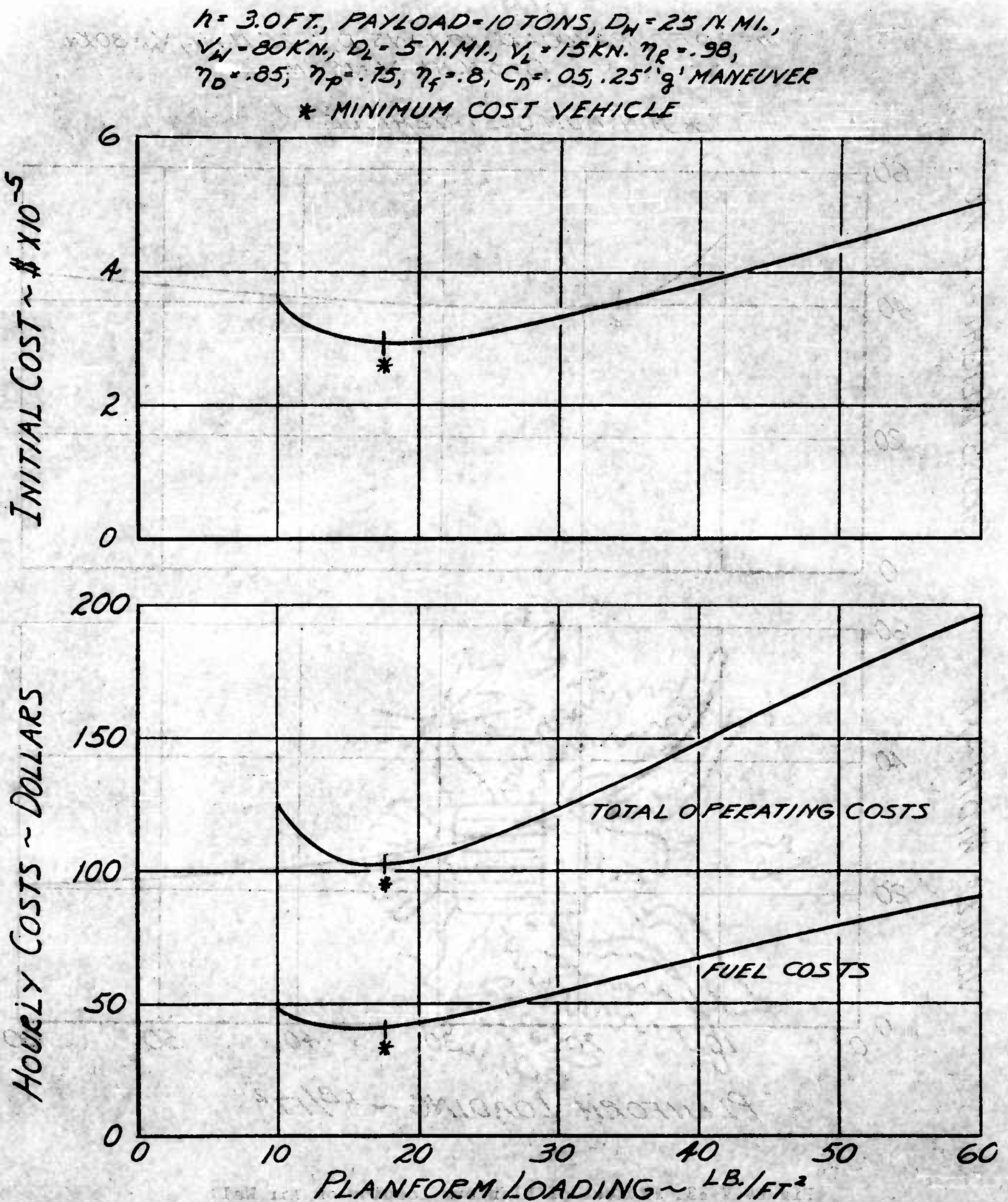


Figure V-32. Effect of Planform Loading on Air Wall Cushion Vehicle Costs.

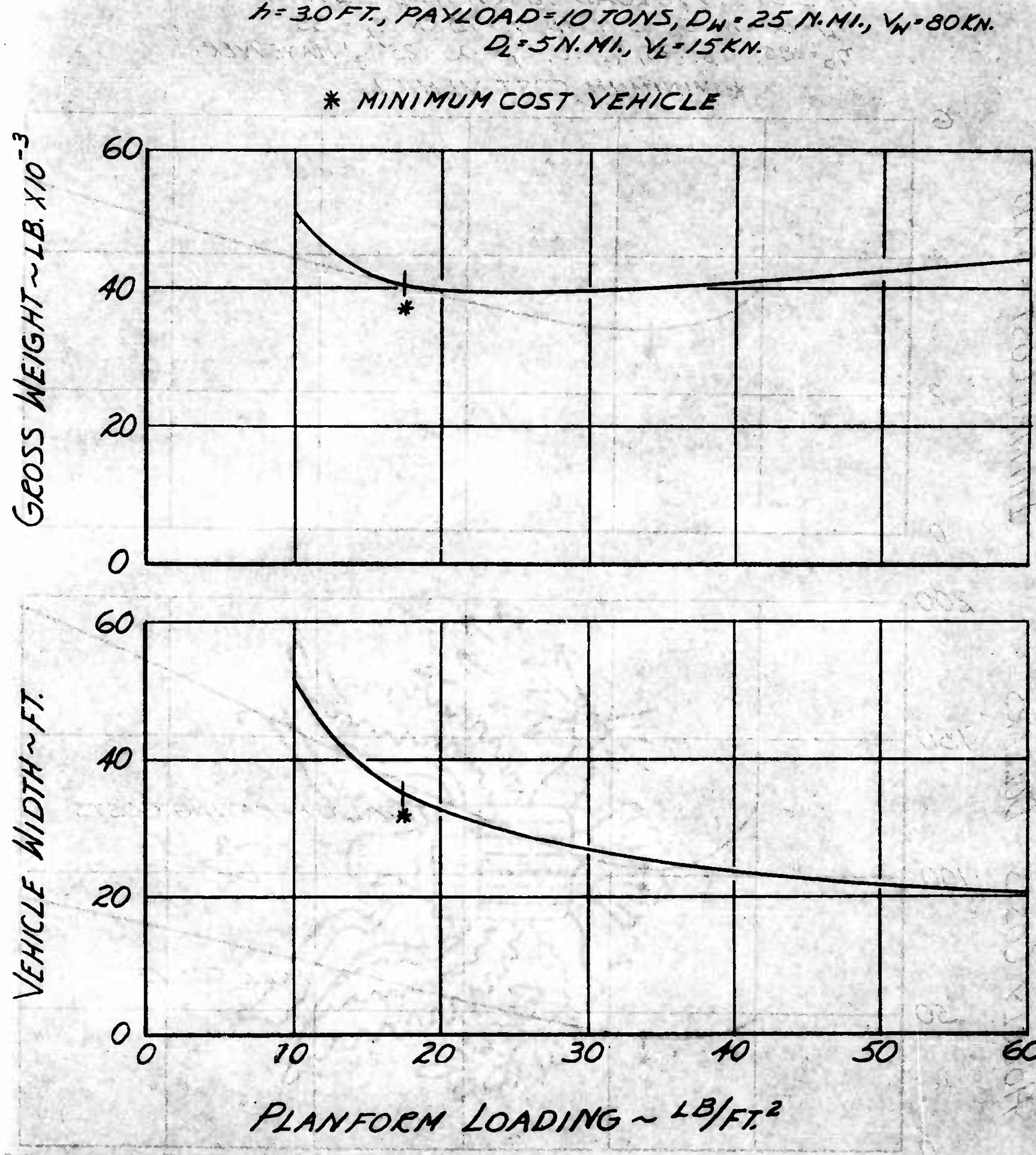


Figure V-33. Effect of Planform Loading on Air Wall Air Cushion Vehicle Size.

greatest power expenditure for the air wall vehicles and, therefore, sizes the installed power. Neither the cruise nor installed power requirements of the minimum cost air wall vehicle are the minimum obtainable. A 3 percent reduction in installed power requirements could be obtained by reducing the planform loading approximately 20 percent. Reduction of the planform loading is not desirable, however, due to the accompanying increase in vehicle size and the lighterage cost increase. Planform loadings exceeding the value resulting in minimum lighterage cost produce significant increases in both cruise and installed power requirements. A 50 percent planform loading increase results in an installed power requirement increase of approximately 18 percent.

The data presenting the effects of planform loading on air wall vehicle characteristics and costs indicates that an analytic procedure for determining characteristics of the vehicle which result in minimum cost also produces a vehicle which closely approximates minimum gross weight, power requirements and fuel requirements. Analytic procedures which seek to minimize either gross weight or power requirements are apt to produce a vehicle which misses the minimum cost by as much as 15 to 20 percent.

The above discussion of the sensitivity of air wall vehicle characteristics and costs to planform loadings is only applicable to vehicles having performance objectives not too dissimilar from those presented. Available data shows that vehicles required to operate at higher heights and for longer mission radii will be more sensitive to planform loading and tend toward lower planform loadings and closer realization of the minimum power and fuel requirements. Vehicles designed to lower operating heights are less sensitive to planform loading, power and fuel requirements and favor higher planform loadings.

g. <u>Payload-Height Relationship</u>

The air wall air cushion vehicle is noted for its ability to carry additional load by reducing its operating height or conversely increases its operating height by reduction

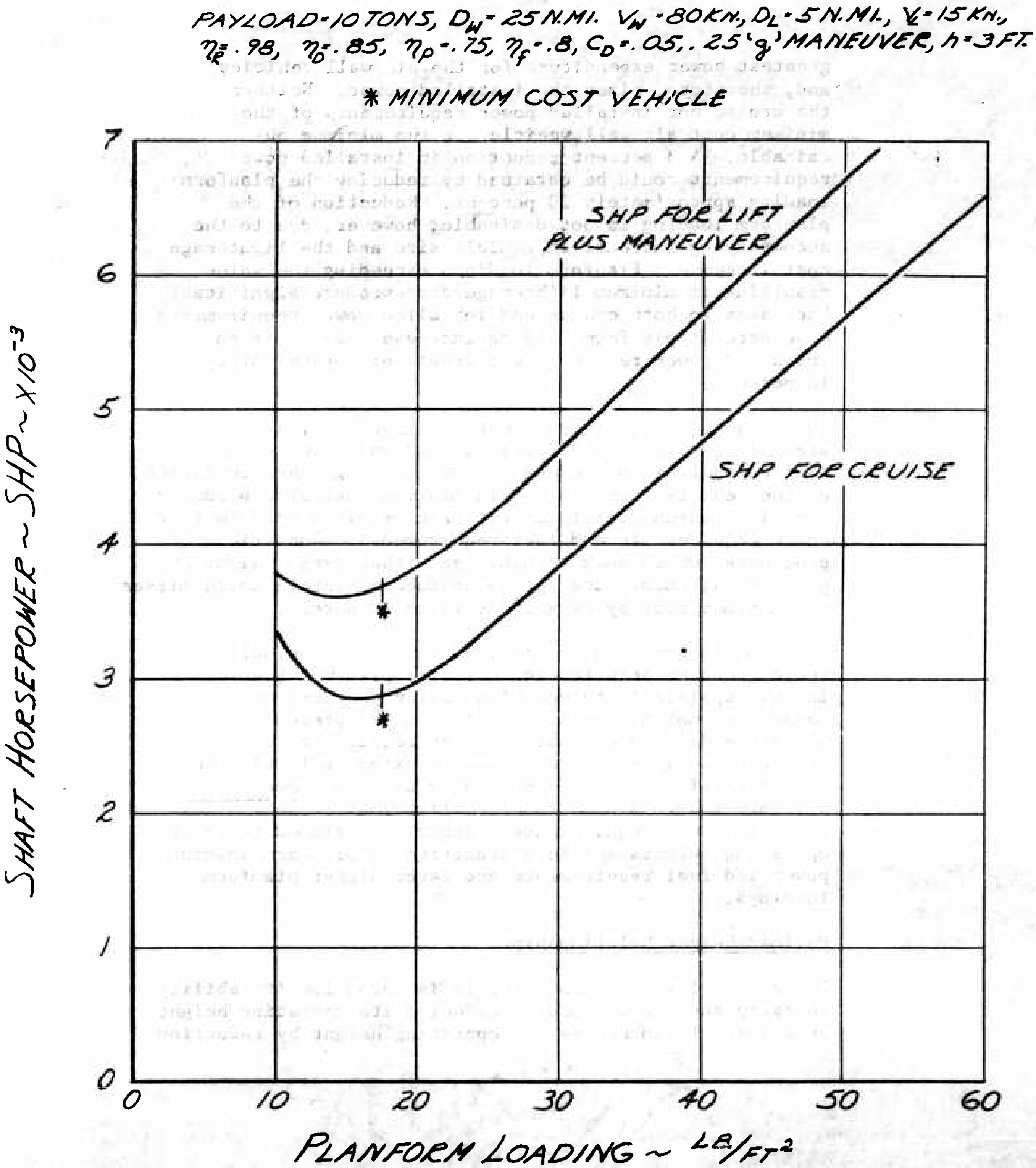


Figure V-34. Effect of Planform Loading Air Wall Air Cushion Vehicle Power Requirements.

in load. The payload-height relationship of the air cushion vehicle is of significant interest in LOTS operations due to the variability of ocean conditions and their possible effects on lighter productivity. As previously discussed and shown on Figure III-16, ship's hatch rate does not degrade until seas with 3.5 significant waves are present. It is desirable, therefore, to maintain design performance capability in seas characterized by 3.5 significant waves. Additionally, it is desired to maintain a level of performance capability commensurate with the ship's off-loading capability in higher wave conditions. Ability to carry greater than design payloads, when environmental conditions permit, is a goal that provides for increased operational economy and increased usefulness through transport of a greater percentage of the larger military cargos.

Figure V-35 presents the payload-height relationship for the minimum lighterage cost air wall vehicle designed for a 3.0 foot operating height. A design operating height of 3.0 feet for air wall vehicles is consistent with ground mobility requirements and impact of less than one out of every one hundred waves in seas characterized by 3.5 foot significant waves. The 3.0 foot design height is, therefore, also consistent with maintaining design performance in the highest seas in which the ship is assumed capable of maintaining its average calm sea hatch rate.

As shown on Figure V-35, reduction of operating height to approximately one-half the design value permits the vehicle to carry twice the design payload. Seas resulting from an 11 knot wind and characterized by 1.8 feet significant waves could still be present. The vehicle would still impact no more than an average of one out of one hundred waves. It is interesting to note that better than the cited condition could be anticipated approximately 20 percent of the time on a world-wide basis. Additionally, in the more favorable locations and seasons, seas characterized by 1.8 foot significant waves can be anticipated better than 40 percent of the time. (See Section III-D)

As shown on Figure III-16 of this report the ship's hatch rate drops sharply with increasing significant wave height

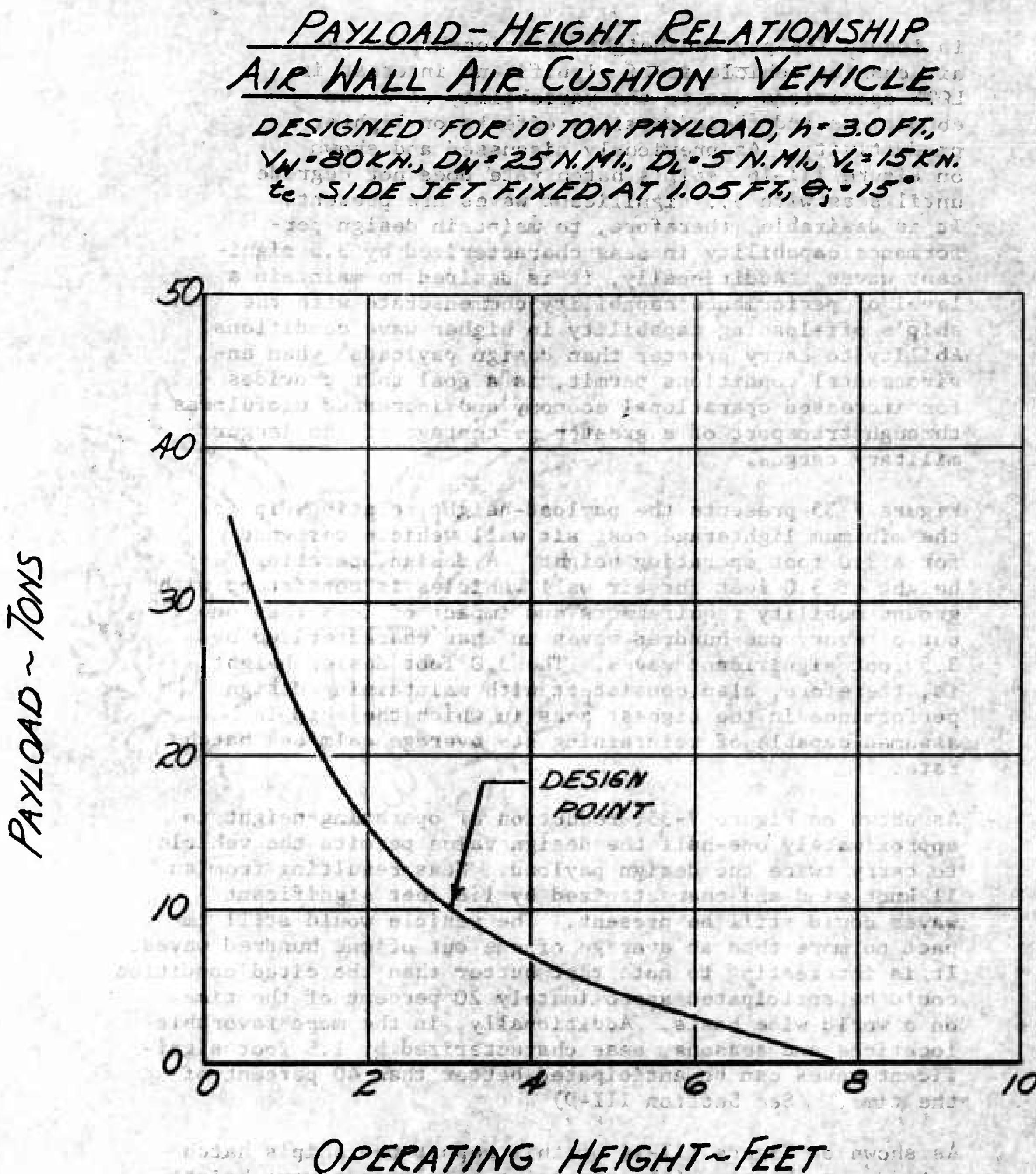

PAYLOAD-HEIGHT RELATIONSHIP
AIR WALL AIR CUSHION VEHICLE
DESIGNED FOR 10 TON PAYLOAD, h = 3.0 FT.,
VH = 80 KN., DH = 25 N.MI., DL = 5 N.MI., VL = 15 KN.
te SIDE JET FIXED AT 1.05 FT., θj = 15°
PAYLOAD ~ TONS
50
40
30
20
10
0
DESIGN POINT
0
2
4
6
8
10
OPERATING HEIGHT ~ FEET

Figure V-35

and cargo unloading ceases when significant wave heights approximating 8 feet are present. The air wall air cushion vehicle is required to have an operating height of 6.3 feet in this environment to maintain an average wave impact frequency of no more than one out of every one hundred waves. Figure V-35 shows that the subject air wall air cushion vehicle is capable of a two ton payload at the 6.3 foot operating height and, therefore, adequately meets the desired performance capabilities in adverse sea environments.

Other factors not withstanding (such as inability of personnel to conduct cargo transfer operations), the air wall vehicle is capable of useful lighterage operations when the most adverse seas which permit ships to off-load their cargo are present. Additionally, it is anticipated that the air wall vehicle can be utilized to carry twice its design payload approximately 30 percent of the time and effect proportionate economic savings during such periods of operation.

h. Hatch Rate Effects

The effect of hatch rate and corresponding unloading rate on lighterage costs of minimum cost air wall vehicles is shown on Figure V-36. The lighterage costs are presented in terms of cost per ton delivered. The lighter is employed in cyclic operation and carries cargo one-way only -- from ship to shore.

Data presented are for vehicles required to have the following performance capabilities:

(1) Five nautical mile land raduis at 15 knots
(2) Twenty-five nautical mile water radius at 80 knots
(3) Three foot operating height.

Two effects of cargo handling rates are shown by Figure V-36. First, increasing hatch rate reduces the cost of cargo delivery. The percentages of cost reduction are dependent upon the vehicle payload. Second, at the lower hatch rates, vehicles with lower payloads become economically more attractive. As hatch rate increases, the higher payloads

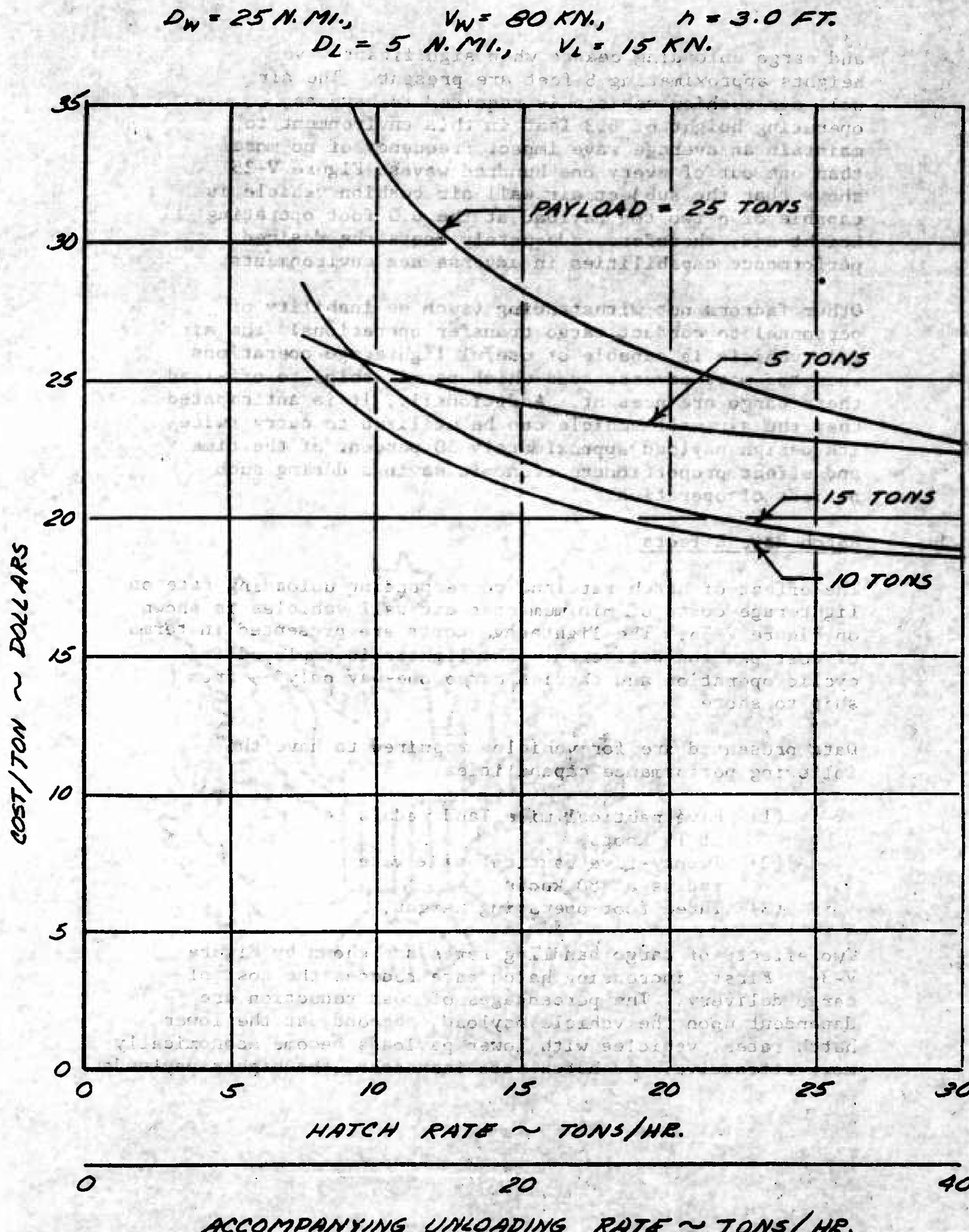


Figure V-36. Effect of Hatch Rate on Lighterage Cost Air Wall Air Cushion Vehicle.

become increasingly more attractive.

At all hatch rates considered, air wall vehicles having a ten-ton payload are economically superior.

Using the nominal hatch rate of 15 tons per hour as a base of reference, a 50 percent reduction in hatch rate to 7.5 tons per hour results in a 22.5 percent increase in lighterage cost. A 50 percent increase in hatch rate results in approximately a 7 percent reduction in cost. The cited percentage changes in cost indicate that the lighterage cost reductions diminish as hatch rates exceed 20 to 30 tons per hour. It must be recognized, however, that other supply system costs, for retaining the ship at discharge site (discussed in Section VII of this report) and for providing the required number of ships in the supply system, are reduced with increasing cargo discharge rates.

2. FULLY FLEXIBLE SKIRTED AIR CUSHION VEHICLES

The following presents a description of investigations of air cushion vehicles employing flexible skirting around the vehicle periphery which just touches the ground.

Study results showing the inter-related effects of fully skirted air cushion vehicle payload, operating height, speed amd mission radii on daily lighterage costs are presented on Figures V-37, V-38 and V-39. The data on these figures represents fully skirted vehicles having minimum lighterage costs for the parametrically assigned speed, payload, operating height and mission radii requirements. Results presented embody the nominal assumptions and estimates presented in Section V E of this report.

The hydrodynamic drag coefficient applied to each vehicle is consistent with the significant wave height. Its design operating height permits hard structure to clear all except one out of one hundred waves. The variation of hydrodynamic drag coefficient and significant wave height with operating height has been previously presented on Figures V-1 and V-3.

The minimum lighterage cost fully skirted vehicles only exceeded the transhipment imposed 35 foot maximum width

limitations for the combinations of largest payloads (25 tons), largest water radius (75 nautical miles) and higher operating heights (above 3.0 feet).

The data presented on Figure V-37 is for fully skirted vehicles operated 5 n. miles inland and 5 n. miles overwater. The cited data show minimum lighterage costs are obtained with fully skirted vehicles having overwater speeds of 20 knots and payloads of approximately 10 tons.

Figure V-38 presents skirted vehicle lighterage cost data for a water radius of 25 n. miles. Skirted vehicles with a 15 ton payload and water speed of 40 knots provide minimum lighterage costs at the 25 n. mile water radius.

Skirted vehicles at operating heights exceeding 1 foot, having a payload of approximately 25 tons and a water speed of 40 knots, provide minimum lighterage costs at an over water radius of 75 n. miles. The lighterage cost data for skirted vehicles designed to 75 n. mile water radius are shown on Figure V-39.

The inter-related effects of fully skirted vehicle design performance capabilities on lighterage costs are graphically shown by the referenced data. Dependent on the design over water radius and operating heights, skirted vehicles having design payloads varying from 10 tons to 25 tons and speeds varying from 20 knots to slightly in excess of 40 knots, provide minimum lighterage costs.

Fully skirted vehicles having a design over water radius of 25 n. miles are selected for further comparison and sensitivity analysis. Reasons for selecting the 25 n. mile over water radius are those previously stated in the Section on results of air-wall air cushion vehicle analysis. Skirted vehicle comparison and sensitivity studies are further limited to vehicles with a 15 ton payload and 40 knot over water speed which is consistent with obtaining minimum lighterage cost at the 25 n. mile water radius.

a. <u>Fully Skirted Vehicle Characteristics</u>

The significant physical characteristic data for minimum lighterage cost fully skirted

SKIRTED AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR/YR.; MAINTENANCE + ATTRITION = 55% INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = S[2+.67(4/s)^.5]; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 'g'; JET ANGLE = 0°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 5 N.MI.

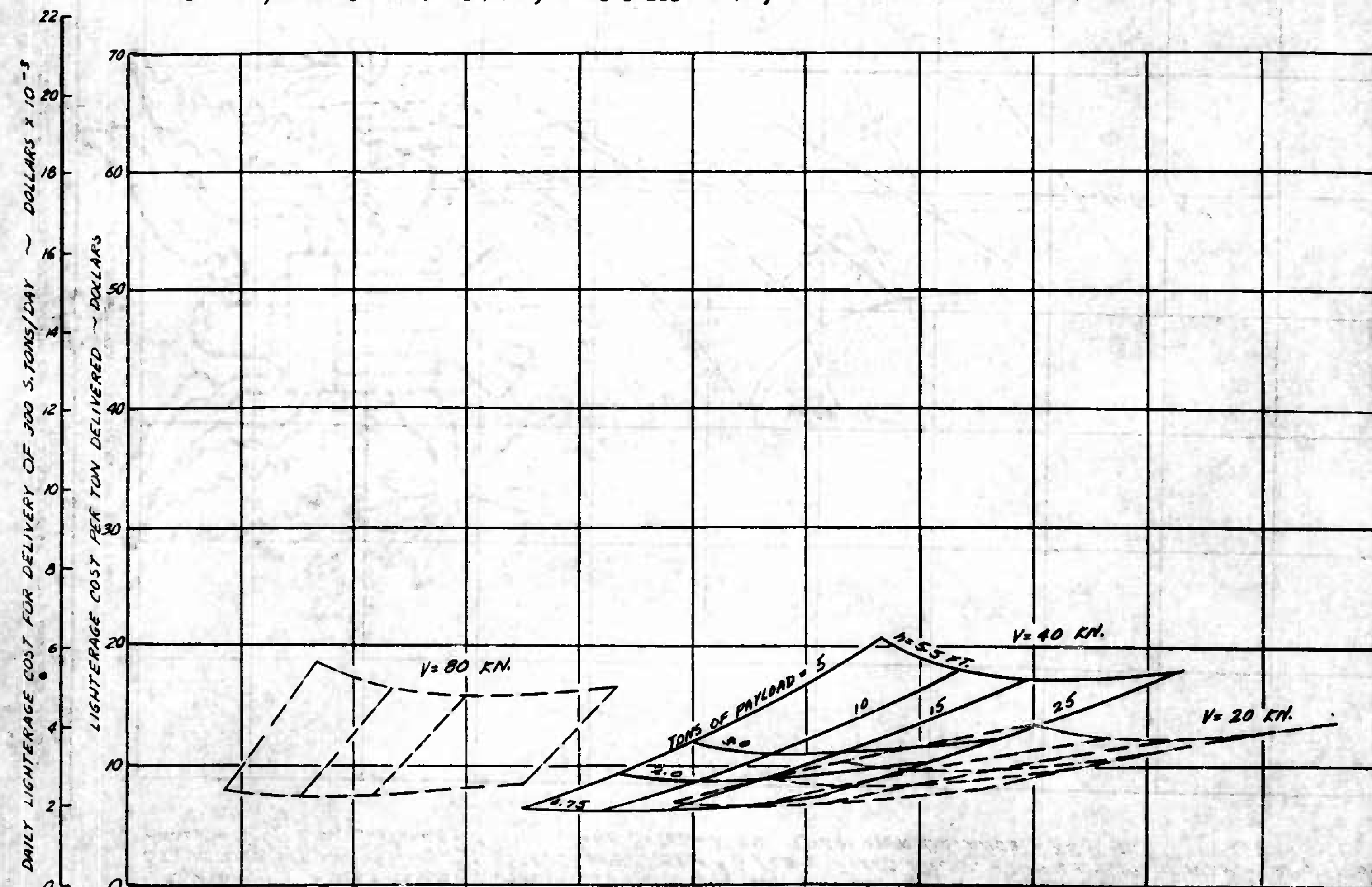


Figure V-37

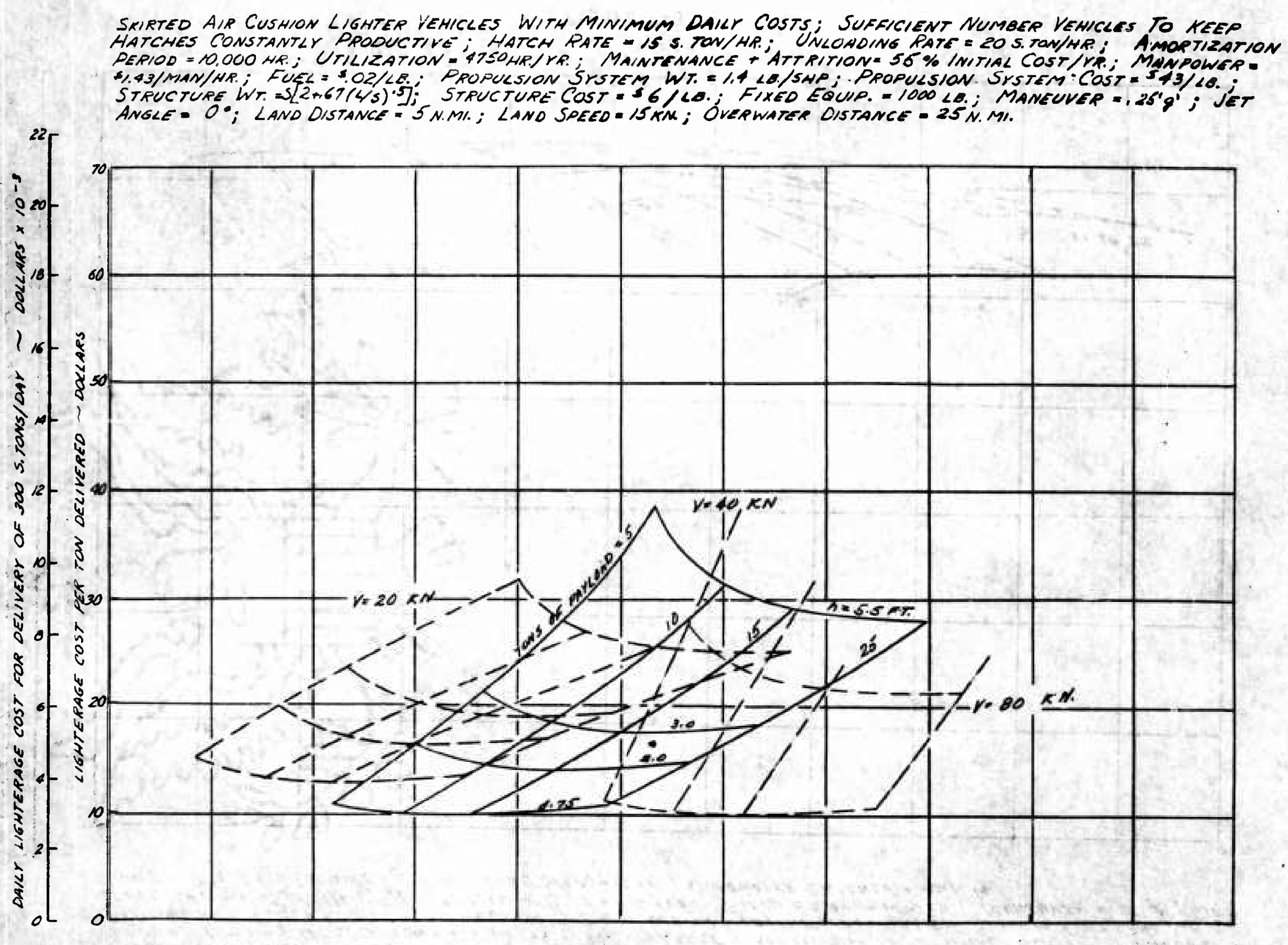

SKIRTED AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 56% INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+67(l/s)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 0°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.
DAILY LIGHTERAGE COST FOR DELIVERY OF 300 S. TONS/DAY ~ DOLLARS x 10^-3
LIGHTERAGE COST PER TON DELIVERED ~ DOLLARS
V = 20 KN
V = 40 KN
V = 80 KN.
TONS OF PAYLOAD = 5
10
15
25
h = 5.5 FT.
3.0
2.0
1.75
0
2
4
6
8
10
12
14
16
18
20
22
0
10
20
30
40
50
60
70

Figure V-38

SKIRTED AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 55 % INITIAL COST/YR.; MANPOWER = \$1.43/MAN/HR.; FUEL = \$.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = \$43/LB.; STRUCTURE WT. = 5[2+.67(4/S)^.5]; STRUCTURE COST = \$6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25g'; JET ANGLE = 0°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 75 N.MI.

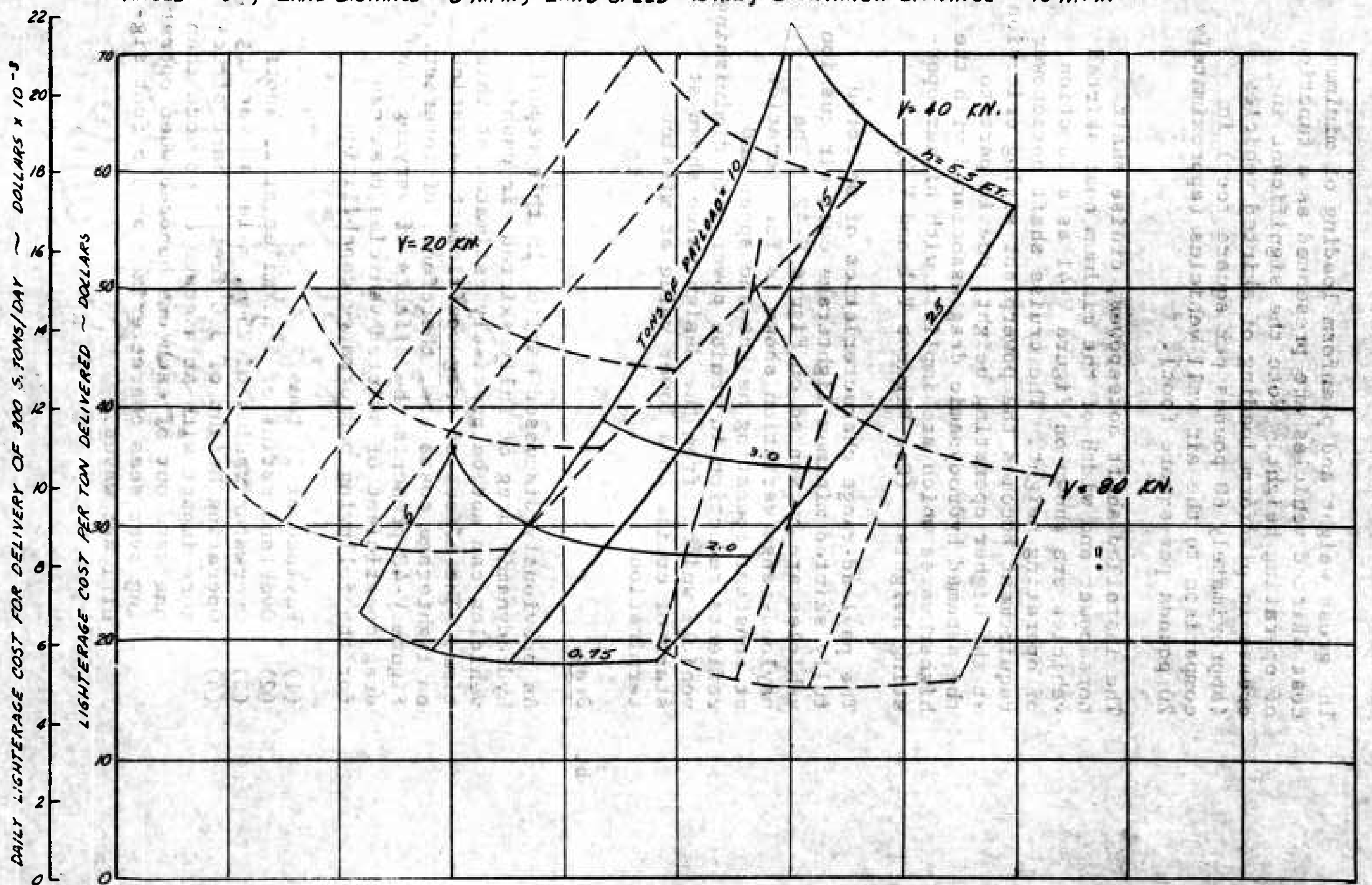


Figure V-39

vehicles are presented on Figures V-40 and V-41.

The gross weight and planform loading of minimum cost skirted vehicles are presented as a function of operating height. Note the significant increase in planform loading of skirted vehicles (approximately 60 pounds per square foot) in comparison to the air wall vehicles (approximately 20 pounds per square foot).

The installed shaft horsepower, cruise shaft horsepower and width of the minimum cost skirted vehicles are shown on Figure V-41 as a function of operating height. The cruise shaft horsepower requirement becomes the powerplant sizing criterion at the higher operating height, due in part to the assumed hydrodynamic drag associated with the higher waves which are implicit with higher operating heights. (See Figures V-1 and V-3).

The payload-range characteristics of selected fully skirted minimum lighterage cost air cushion vehicles are presented on Figure V-42. The payload-range variation shown is for operation at constant operating height and speed and reflects reduction in cruise power with diminishing vehicle weight; from the design value shown at start of cruise to a lower value at mission termination.

b. <u>Drag</u>

As previously discussed earlier in this report, hydrodynamic drag of fully skirted air cushion vehicles can not be precisely estimated at this time. The effect of drag coefficient variation on lighterage costs are, therefore, of interest. Figure V-43 presents the effects of varying the drag coefficient of skirted vehicles designed for the following performance capabilities.

(1) Payload of 15 tons
(2) Overland radius of 5 n. miles at 15 knots
(3) Overwater radius of 25 n. miles at varying speed
(4) Operating height of 3.0 feet -- hard structure impact with an average of no more than one wave out of each one hundred when operating over seas characterized by 3.5 foot significant waves.

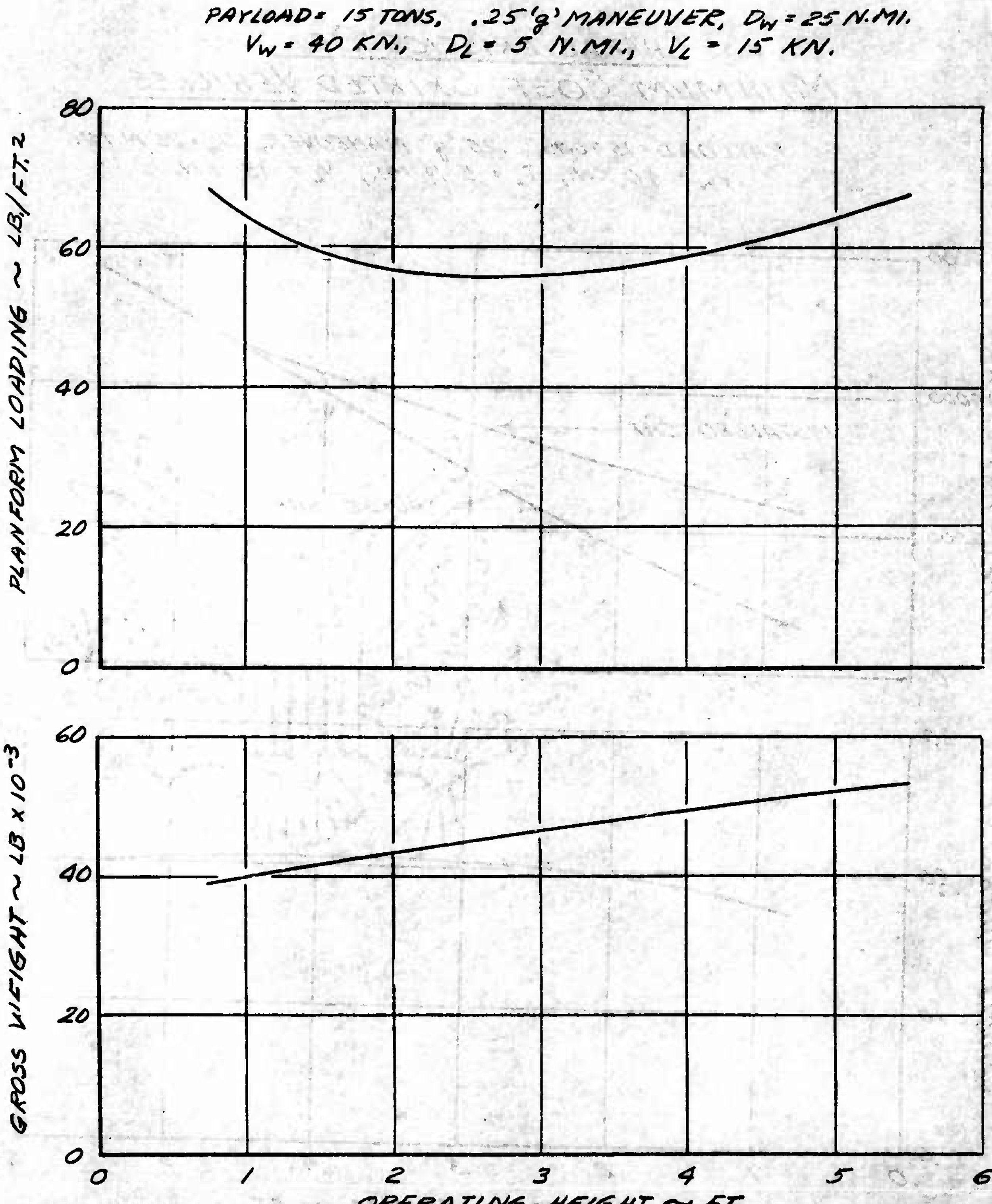


Figure V-40. Characteristics of Minimum Cost Skirted Vehicles.

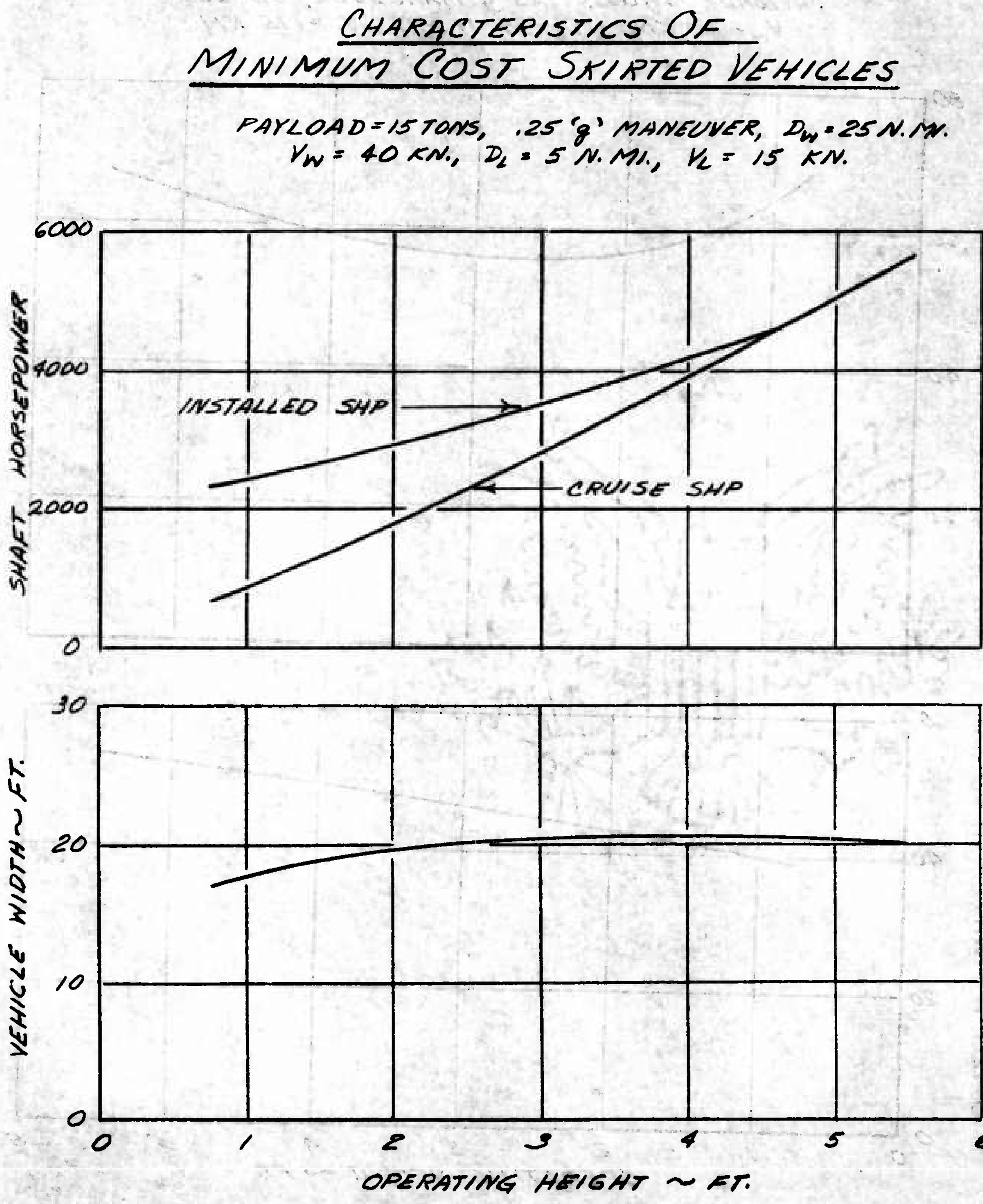

CHARACTERISTICS OF
MINIMUM COST SKIRTED VEHICLES
PAYLOAD=15 TONS, .25 'g' MANEUVER, D_W=25 N.MI.
V_W = 40 KN., D_L = 5 N.MI., V_L = 15 KN.
SHAFT HORSEPOWER
6000
4000
2000
0
INSTALLED SHP
CRUISE SHP
VEHICLE WIDTH ~ FT.
30
20
10
0
0
1
2
3
4
5
6
OPERATING HEIGHT ~ FT.

Figure V-41

SKIRTED AIR CUSHION VEHICLES
PAYLOAD - RANGE RELATIONSHIPS

$V = 40$ KN., $C_D = .00052\ ^{P_W}/_{P_A}\ h_{W_{33}} + .05$

VEHICLES DESIGNED FOR RADIUS MISSION

$D_L = 5$ N.MI., $D_W = 25$ N.MI., NOMINAL PAYLOAD = 15 T.

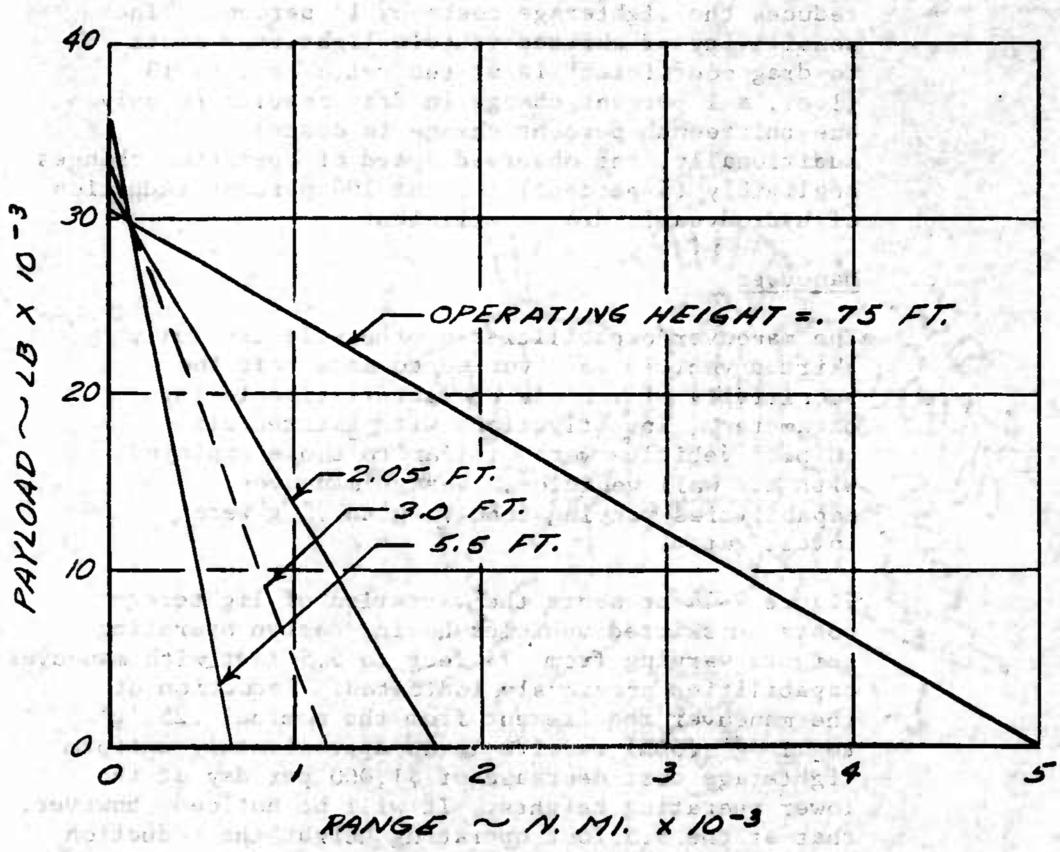


Figure V-42

The drag coefficients shown on Figure V-43 include both hydrodynamic and aerodynamic components and are based on the density of air (.002378 slugs/ft^3) as opposed to the water density (2 slugs/ft^3). The nominal 3.0 foot operating height drag coefficient corresponds to the C_D value of 2.0 shown on Figure V-43.

A 50 percent increases in drag coefficient serves to reduce the desired operating speed from 40 knots to 30 knots and increases the daily lighterage costs by only 7 percent. A reduction in drag coefficient by 100 percent increases the desired operating speed to approximately 42 knots and reduces the lighterage costs by 13 percent. The sensitivity of skirted vehicle lighterage costs to drag coefficient is at the ratio of 1 to 13 (i.e., a 1 percent change in drag results in only one-thirteenth percent change in costs). Additionally, the observed speed of operation changes negligibly (5 percent) for the 100 percent reduction of hydrodynamic drag coefficient.

c. <u>Maneuver</u>

The maneuver capabilities of the selected fully skirted vehicle were varied to ascertain the sensitivity of vehicle characteristics to this parameter. Investigations with skirted air cushion vehicles were similar to those employed with air wall vehicles. Design maneuver capabilities varying from .1 'g' to .5 'g' were investigated.

Figure V-44 presents the variation of lighterage costs for skirted vehicles having design operating heights varying from .75 feet to 5.5 feet with maneuver capabilities previously indicated. Reduction of the maneuver requirement from the nominal .25 'g' to .1 'g' (60%) results in an approximately uniform lighterage cost decrease of $1,000 per day at the lower operating heights. It will be noticed, however, that at the 5.5 foot operating height the reduction in maneuver capability to .1 'g' results in no change in lighterage costs. Increasing the maneuver

EFFECT OF WATER DRAG COEFFICIENT ON SKIRTED VEHICLE DAILY LIGHTERAGE COSTS

PAYLOAD = 15 TON, h = 3.0 FT., D_W = 25 N.MI.
D_L = 5 N.MI., V_L = 5 KN.

$$C_D = C_{D_W} \frac{\rho_W}{\rho_A} + .05$$

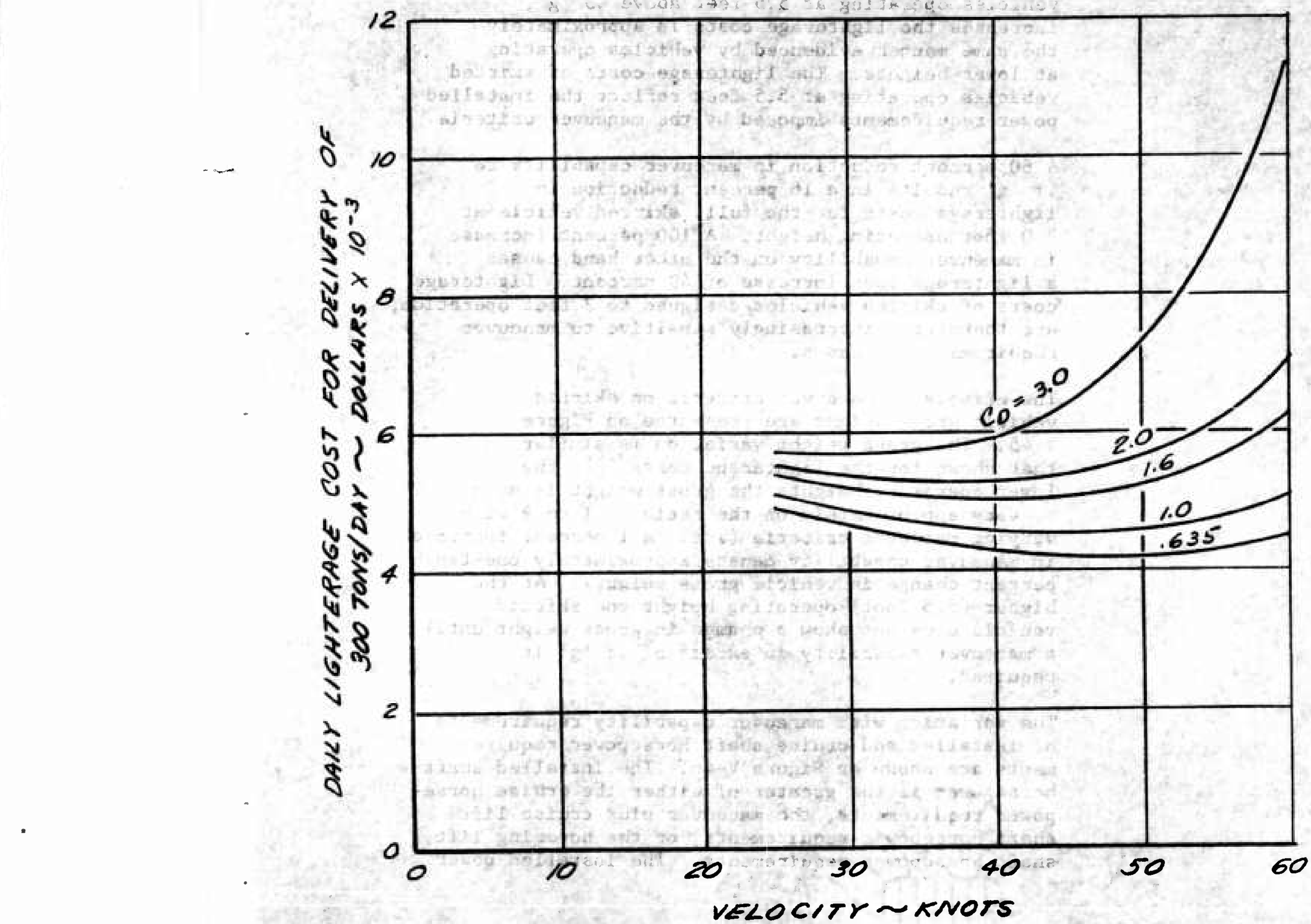


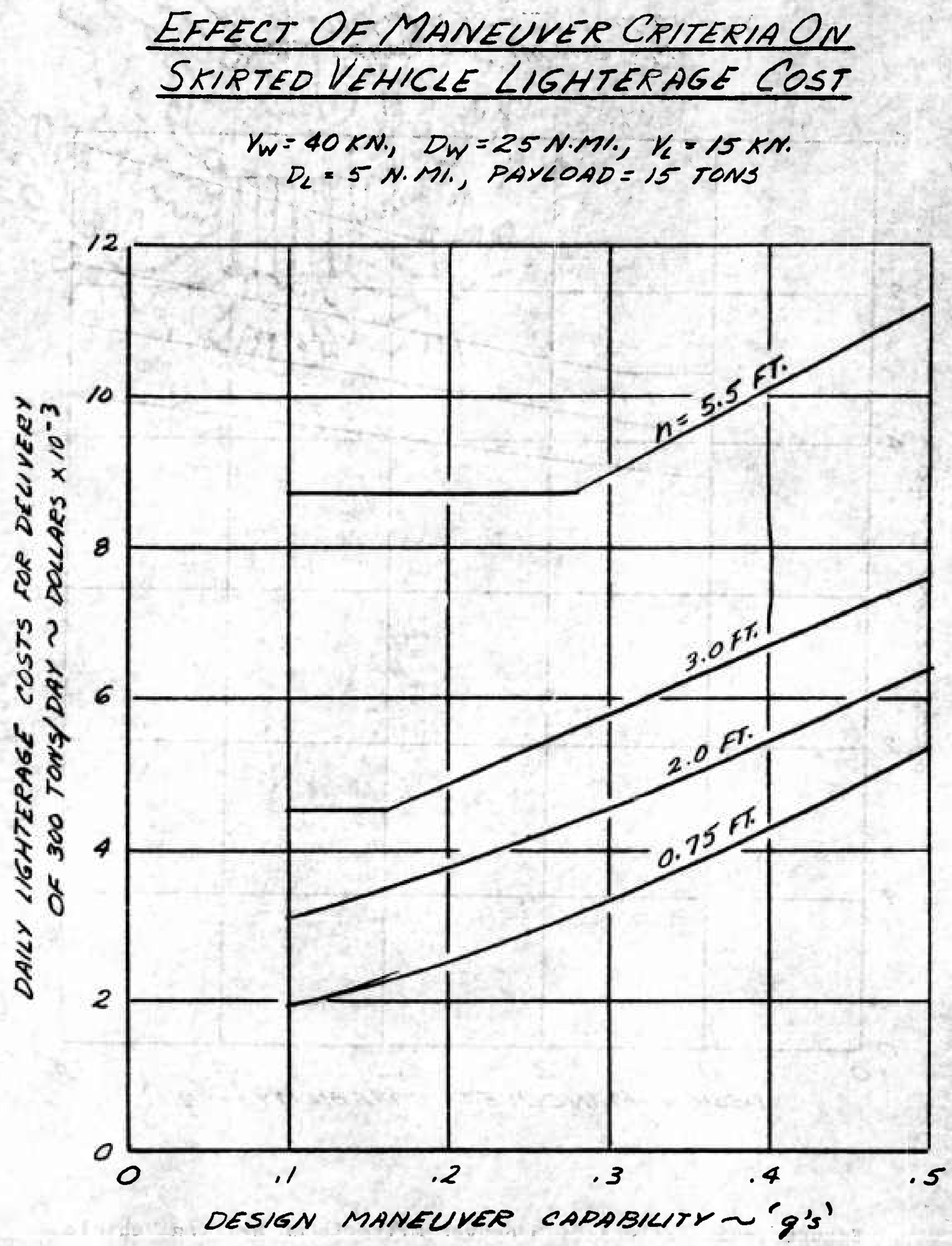
Figure V-43

capability from the nominal .25 'g' to .5 'g' (100% increase) results in an approximately uniform increase of $2,500 in the lighterage costs for vehicles with lower operating heights. At the higher (5.5 foot) operating height no significant cost increase accompanies an increasing maneuver capability requirement until a .3 'g' maneuver capability is imposed. Increasing the maneuver requirements of skirted vehicles operating at 5.5 feet above .3 'g', increases the lighterage costs in approximately the same manner evidenced by vehicles operating at lower heights. The lighterage costs of skirted vehicles operating at 5.5 feet reflect the installed power requirements imposed by the maneuver criteria.

A 60 percent reduction in maneuver capability to .1 'g' results in a 16 percent reduction in lighterage costs for the fully skirted vehicle at 3.0 foot operating height. A 100 percent increase in maneuver capability on the other hand causes a lighterage cost increase of 49 percent. Lighterage costs of skirted vehicles designed to 3 feet operation, are therefore, increasingly sensitive to maneuver requirement increases.

The effects of maneuver criteria on skirted vehicle gross weight are presented on Figure V-45. The gross weight variation is similar to that shown for the lighterage costs. At the lower operating heights the gross weight is seen to vary approximately on the ratio of 1 to 9 with varying maneuver criteria (i.e., a 1 percent increase in maneuver capability causes approximately one-tenth percent change in vehicle gross weight). At the higher (5.5 foot) operating height the skirted vehicle does not show a change in gross weight until a maneuver capability in excess of .3 'g' is required.

The variation with maneuver capability requirements of installed and cruise shaft horsepower requirements are shown on Figure V-46. The installed shaft horsepower is the greater of either the cruise horsepower requirements, the maneuver plus cruise lift shaft horsepower requirements, or the hovering lift shaft horsepower requirements. The installed power



EFFECT OF MANEUVER CRITERIA ON
SKIRTED VEHICLE LIGHTERAGE COST
V_W = 40 KN., D_W = 25 N·MI., V_L = 15 KN.
D_L = 5 N. MI., PAYLOAD = 15 TONS
DAILY LIGHTERAGE COSTS FOR DELIVERY OF 300 TONS/DAY ~ DOLLARS x 10^{-3}
DESIGN MANEUVER CAPABILITY ~ 'g's'
h = 5.5 FT.
3.0 FT.
2.0 FT.
0.75 FT.
0
2
4
6
8
10
12
.1
.2
.3
.4
.5

Figure V-44

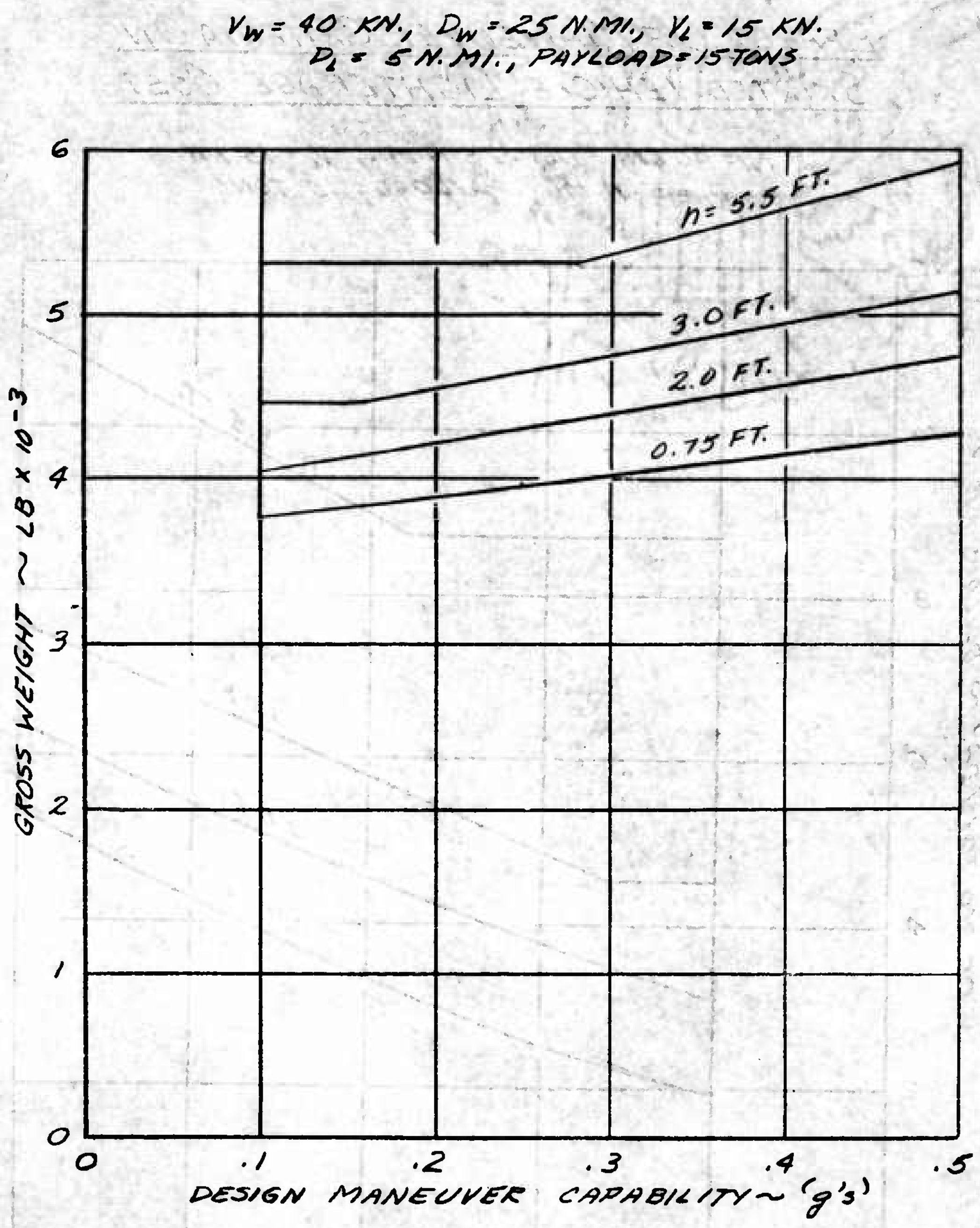


Figure V-45. Effect of Maneuver Criteria on Skirted Vehicle Gross Weight.

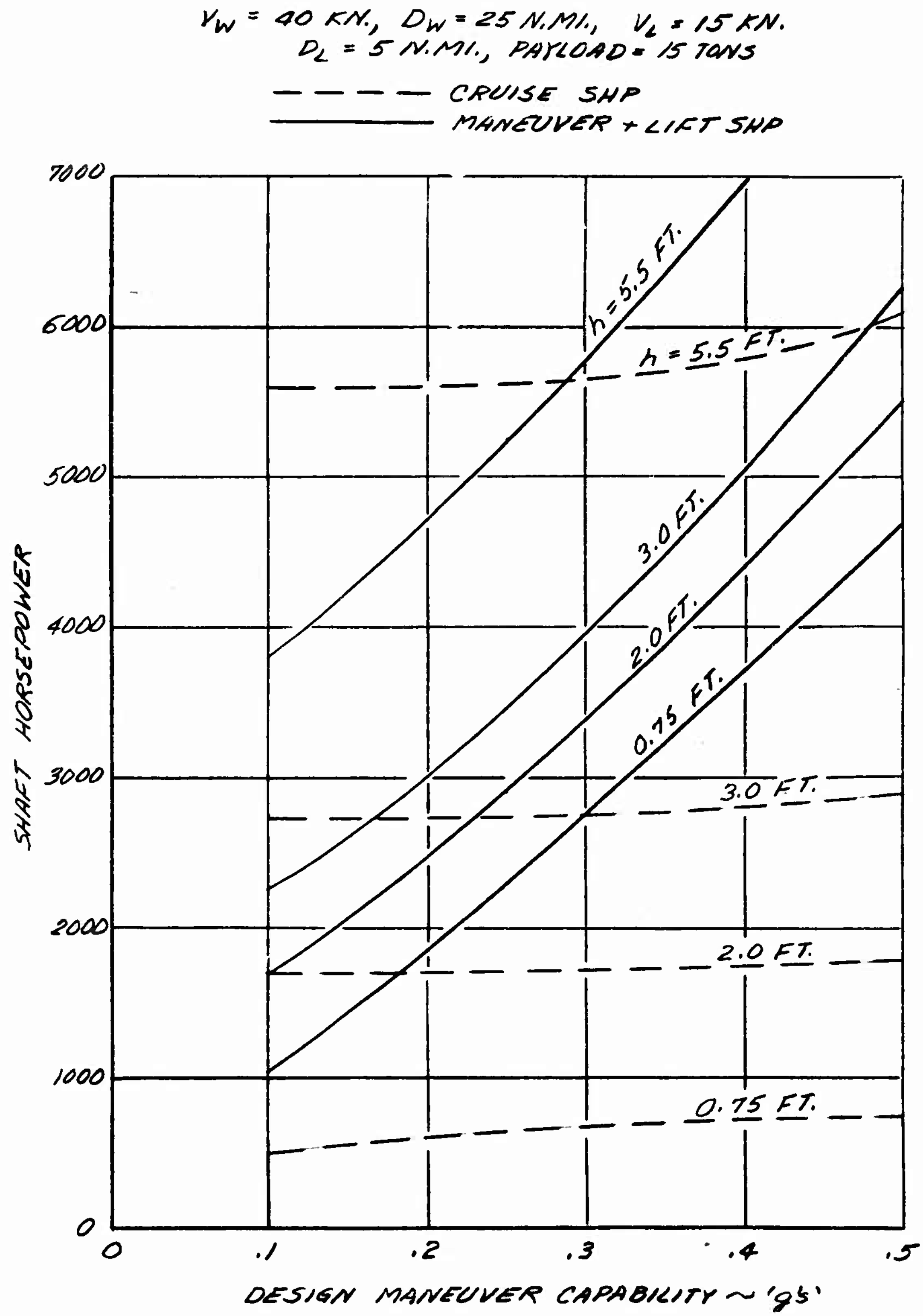


Figure V-46. Effect of Maneuver Criteria on Skirted Vehicle Power Requirements.

Penalties associated with increasing maneuver requirements are clearly shown by the data on Figure V-46. The cited figure shows that maneuver requirements approximating .1 'g' at the low operating heights and .3 'g' at the higher operating heights can be achieved with powerplants satisfying the cruise power requirements. Maneuver capability requirements in excess of .1 'g' to .3 'g' cause larger power plants to be installed in the skirted vehicles and causes the increased vehicle weights and costs shown on Figures V-44 and V-45. Utilizing the skirted vehicle designed to 3 foot operating height as a base of reference, Figure V-46 shows that an increase in maneuver capability from .25 'g' to .5 'g' results in a 2,800 shaft horsepower increase of installed power (81 percent). A reduction in maneuver requirements to .17 'g' provides for a corresponding 20 percent reduction in installed power (700 shaft horsepower). Further reduction of maneuver capability requirement for this vehicle is not warranted, however, since the cruise power requirements become the determining factor in sizing the vehicle's powerplant below .17 'g'.

The importance of establishing ACV maneuver requirements which are no more stringent than necessary to achieve successful and useful operation is demonstrated by the foregoing skirted vehicle data and the previously discussed and corresponding air wall vehicle data.

d. Propulsion

Variations to propulsion system cost, weight and propulsive efficiency were explored to determine the fully skirted vehicle's sensitivity to these parameters. The analysis of skirted vehicle sensitivity to propulsion system parameter values is similar and consistent with those performed for air wall vehicles.

Figure V-47 presents the inter-related effects of skirted vehicle propulsion system weight and costs on daily lighterage costs. A 16 percent change in propulsion system costs ($7/lb) above and below the

SKIRTED AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR/YR.; MAINTENANCE + ATTRITION = 55% INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = VAR. LB./SHP; PROPULSION SYSTEM COST = $VAR./LB.; STRUCTURE WT. = S[2+.67(W/S)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 'g'; JET ANGLE = 0°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; WATER SPEED = 40 KN.

EFFECTS OF PROPULSION SYSTEM COST AND WEIGHT

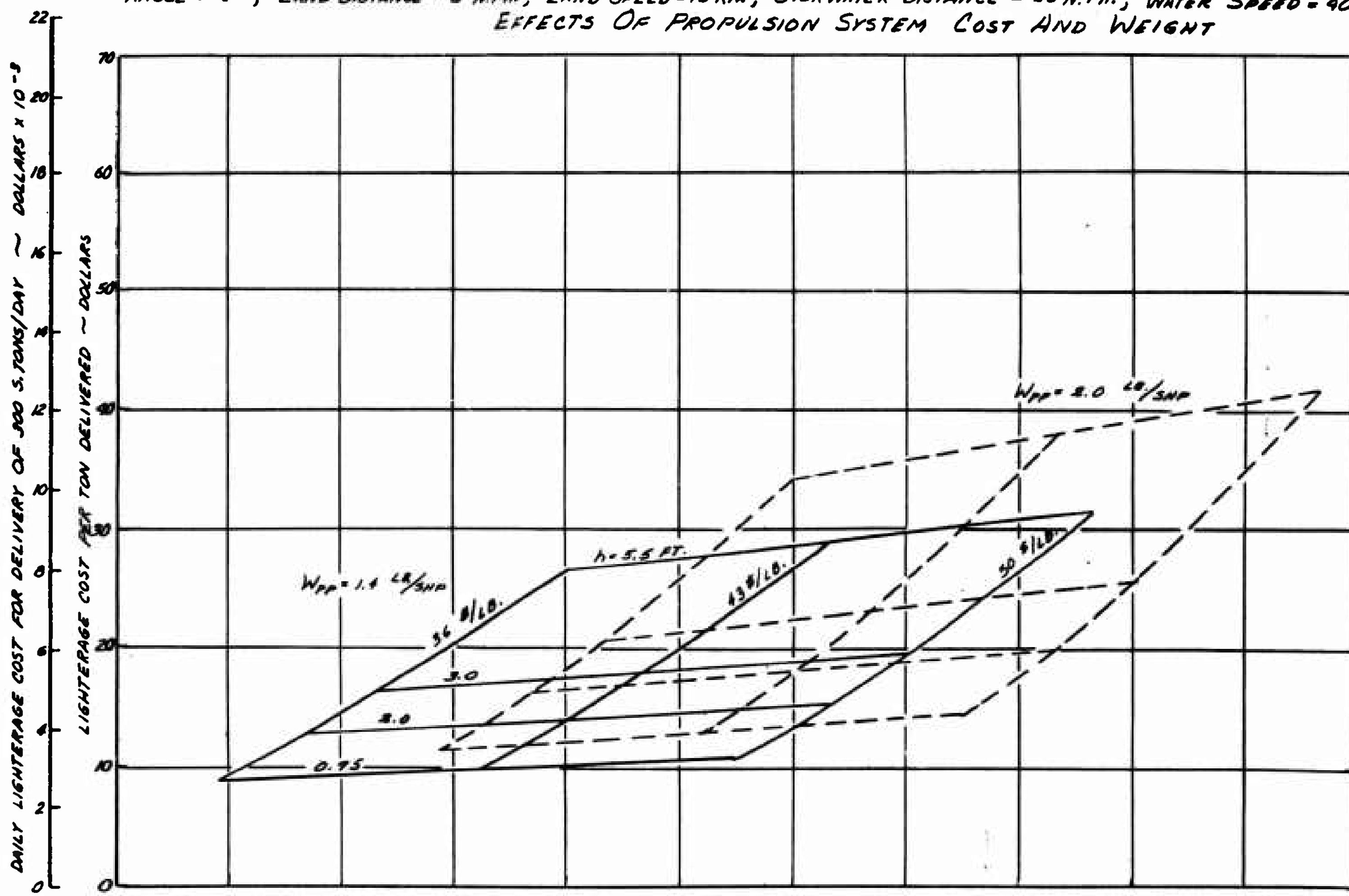


Figure V-47

nominal value ($43/lb) results in approximately an 8 percent change in lighterage costs at a propulsion system weight of 1.4 pounds per shaft horsepower. The same 16 percent change in propulsion system costs produces a 10 percent change in lighterage daily costs at a propulsion system weight of 2.0 pounds per shaft horsepower. The cases investigated show that sensitivity of the skirted vehicles to propulsion system costs is identical to that of the air wall type vehicles.

An increase of propulsion system weight by 43 percent (.6 pounds per shaft horsepower) increases the daily lighterage costs of skirted vehicles approximately 31 percent. The skirted vehicles again demonstrate the same significant sensitivity to the propulsion system weight parameter as air wall vehicles. It is desirable, therefore, to expend greater effort in reduction of skirted vehicle propulsion system weight than cost in the same proportions indicated for the air wall vehicles.

The effect of changes to the propulsive (thrusting) efficiency (η_p) of the skirted vehicle's propulsion system were also investigated. As previously indicated, these changes can be interpreted as an equivalent change in vehicle drag.

The effects of a 50 percent propulsive efficiency on skirted vehicle lighterage costs are shown on Figure V-48. The one-third reduction in propulsive efficiency from the nominal value of 75 percent propulsive efficiency produces cost increases which are an increasingly higher percentage as the vehicle operating height varies from .75 feet to 5.5 feet. At the 5.5 foot operating height, a 30 percent lighterage cost increase is evidenced. The lighterage costs increase 17 percent at the 3.0 foot operating height.

The gross weight and planform loading of minimum lighterage cost skirted vehicles with a 50 percent propulsive efficiency are shown on Figure V-49. Comparison of data on Figure V-49 with corresponding data for skirted vehicles with 75 percent propulsive

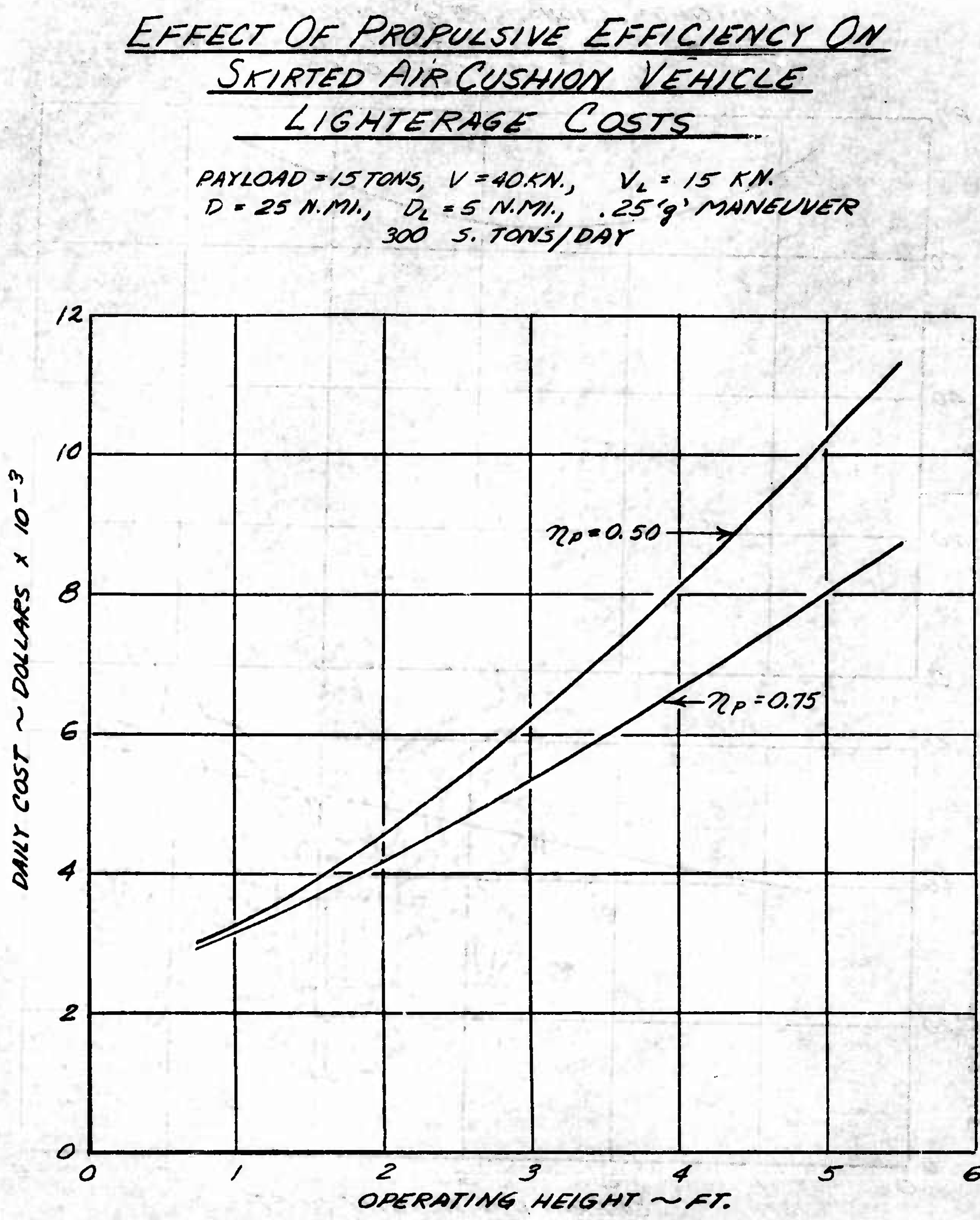

EFFECT OF PROPULSIVE EFFICIENCY ON
SKIRTED AIR CUSHION VEHICLE
LIGHTERAGE COSTS
PAYLOAD = 15 TONS, V = 40 KN., V_L = 15 KN.
D = 25 N.MI., D_L = 5 N.MI., .25 'g' MANEUVER
300 S. TONS/DAY
DAILY COST ~ DOLLARS x 10^{-3}
OPERATING HEIGHT ~ FT.
η_p = 0.50
η_p = 0.75
0
2
4
6
8
10
12
0
1
2
3
4
5
6

Figure V-48

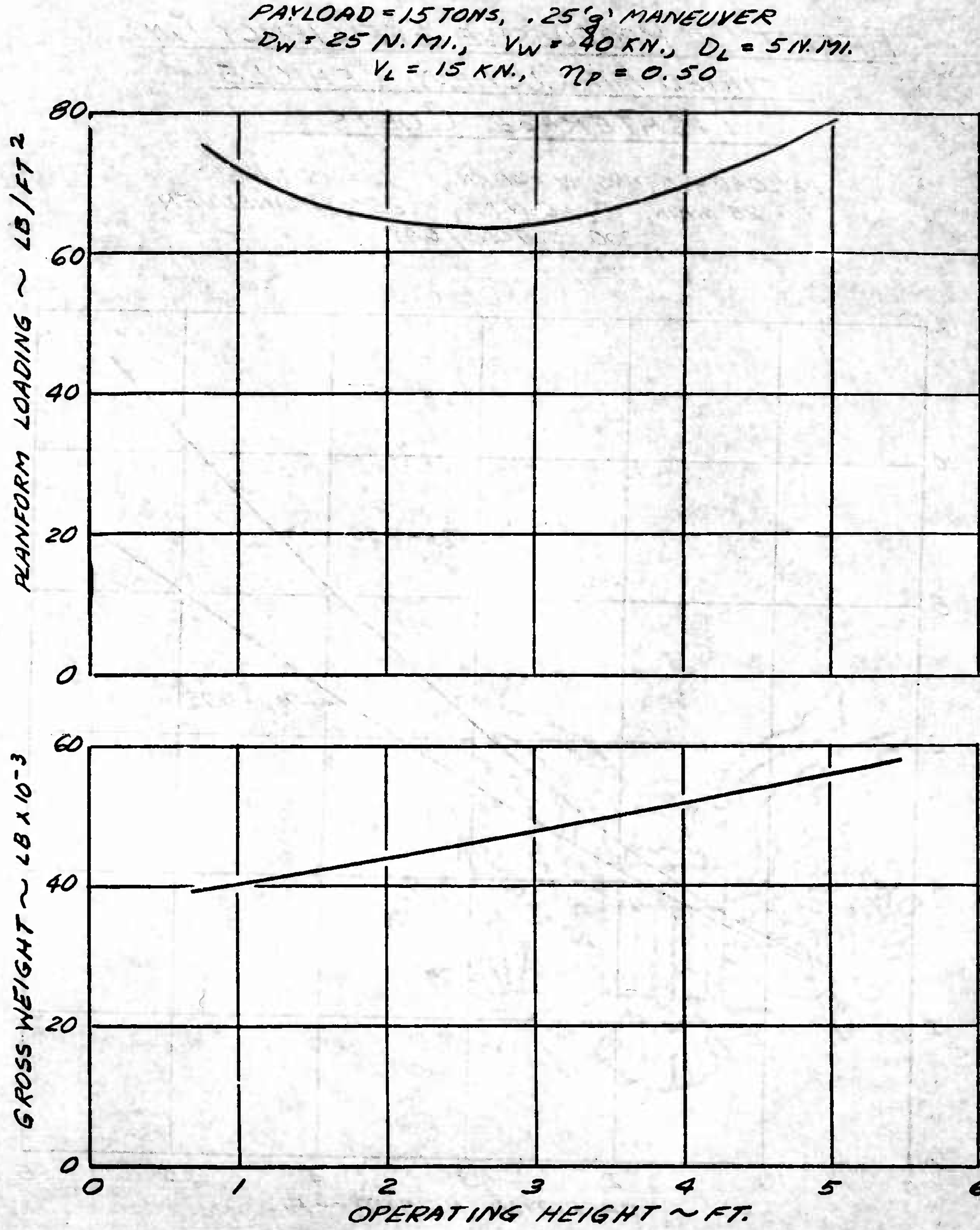


Figure V-49. Propulsive Efficiency Effects on Characteristics of Minimum Cost Skirted Vehicles.

efficiency (on Figure V-40) reveals that the gross weight of skirted vehicles at 3.0 foot operating height increases approximately 4.5 percent due to the propulsive efficiency degradation. The reduced propulsive efficiency causes vehicle gross weight increases from zero percent at a 1.0 foot operating height to approximately 9.5 percent at a 5.5 foot operating height. The planform loading of skirted vehicles with 50 percent propulsive efficiency increases a similar percentage, however, and the vehicle width remains virtually unchanged as comparison of data on Figure V-41 and V-50 show.

The cruise power requirements of skirted vehicles show the most significant increase due to a propulsive efficiency decrease. Comparison of the skirted vehicle power requirements shown on Figure V-50 ($\eta_p = .5$) with those on Figure V-41 ($\eta_p = .75$) indicates a 25 percent increase in cruise power requirements for a vehicle designed to a 3.0 foot operating height. Skirted vehicles designed to a 1.0 foot operating height show only small differences in cruise power requirements from the reduced propulsive efficiency. At a 5.5 foot operating height, the cruise power requirements of the skirted vehicles having a 50 percent propulsive efficiency (which are also the installed power requirements at the 5.5 foot operating height) is 32 percent greater than that of the vehicle with a 75 percent propulsive efficiency.

The foregoing leads to the conclusion that no signicant changes in skirted vehicle physical characteristics are caused by degradations in propulsive efficiency approximating 35 percent until operating heights in excess of 3.0 feet are required. The significant effects of propulsive efficiency degradations are in terms of increased fuel consumption which relate to lighterage costs at a sensitivity approximating 50 percent (i.e., a 1 percent reduction in propulsive efficiency causes a one-half percent increase in lighterage costs).

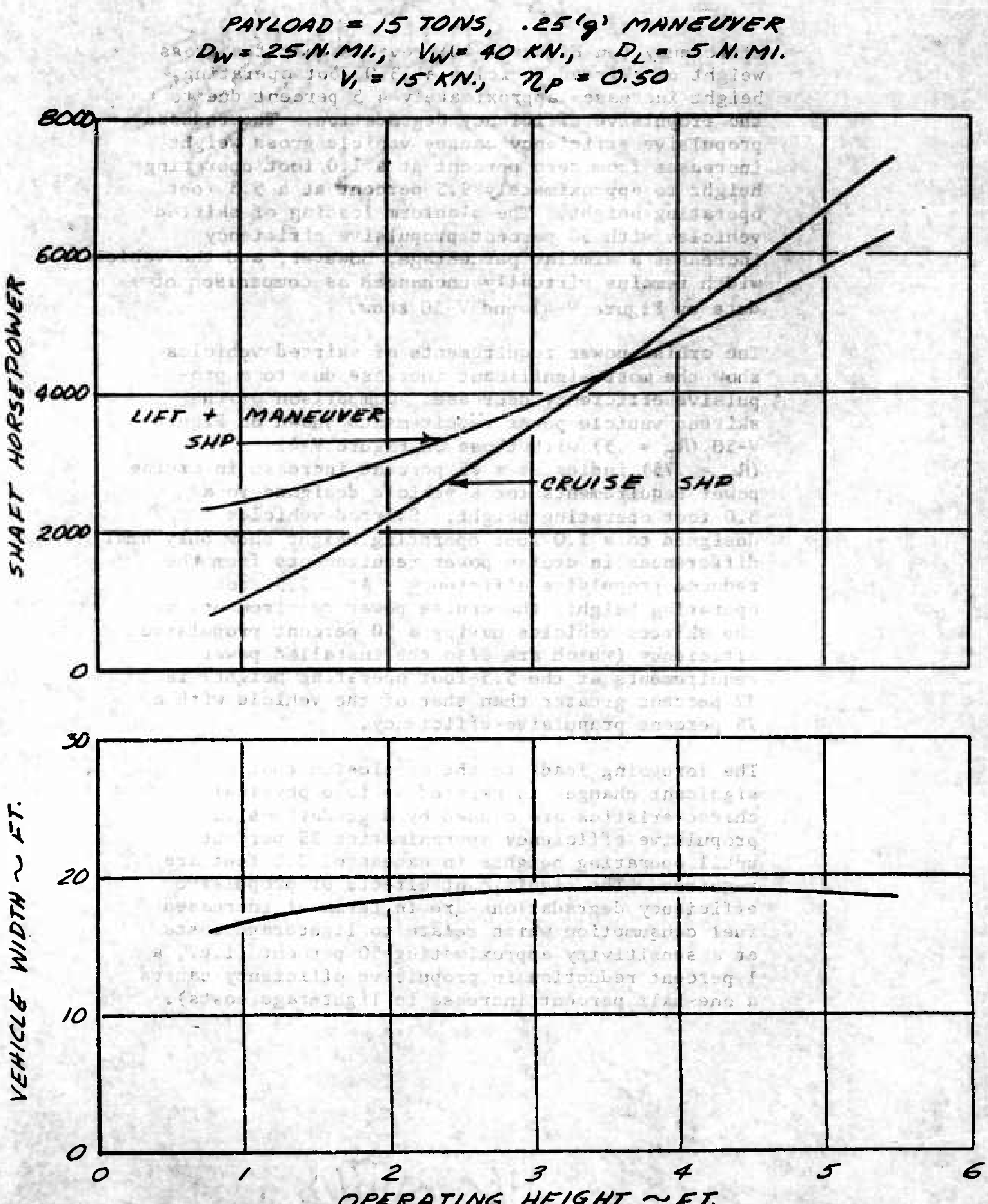


Figure V-50. Propulsive Efficiency Effects on Characteristics of Minimum Cost Skirted Vehicles.

e. Structure

Effects of variations to assumed unit structure weight and unit structure cost of selected skirted vehicles having an operating height of 3.0 feet were determined. The assumed variations are those utilized with air wall vehicles (the nominal weight and those 50 percent greater, in combination with costs of six dollars and fifteen dollars, per pound).

Figure V-51 presents the inter-related effects of unit structure weight and cost on skirted air cushion vehicle daily lighterage costs. For the selected performance requirements the skirted vehicle shows a structure weight sensitivity of approximately 1 to 3.8 (i.e., a 1 percent increase in unit structure weight causes slightly more than one-fourth percent increase in lighterage costs). The data on Figure V-51 also indicates that the skirted vehicle shows a structure cost sensitivity of approximately 1 to 9.5 (i.e., a 1 percent increase in unit structure cost causes slightly more than a one-tenth percent increase in lighterage costs).

The foregoing indicates that in achieving minimum lighterage costs with skirted vehicles considerations of structure weight are more significant than structure cost on a ratio of approximately 1 to 2.5. It will be recalled that air wall vehicles were more sensitive to unit structure weight than unit structure cost on the ratio of 1 to 3.5. Also, the air wall type vehicle is more sensitive to unit structure cost than the skirted vehicles, indicating that the skirted type vehicles are generally slightly less sensitive to assumed structure parameters.

The data presented on Figure V-52 shows the variation of skirted vehicle gross weight and width as functions of unit structure weight and cost. The skirted vehicle gross weight is virtually unaffected by unit structure cost but reflects a sensitivity to unit structure weight at the ratio of approximately 1 to 7. Vehicle width is shown to decrease slightly with increasing structure weight and cost, reflecting a 1 to 7 sensitivity to unit structure weight and a 1 to 25

EFFECT OF STRUCTURE WEIGHT AND COST ON SKIRTED AIR CUSHION VEHICLE DAILY COSTS

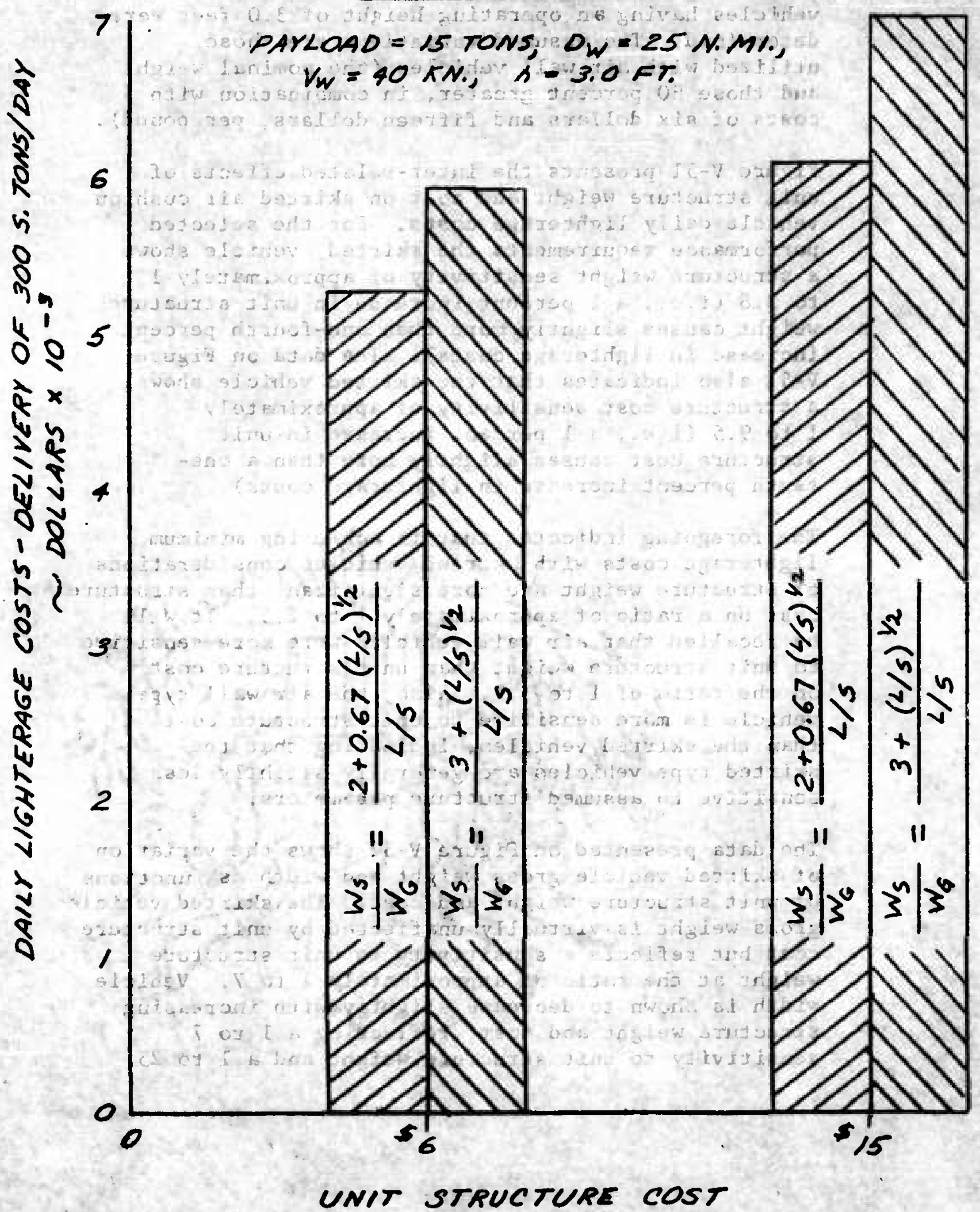


Figure V-51

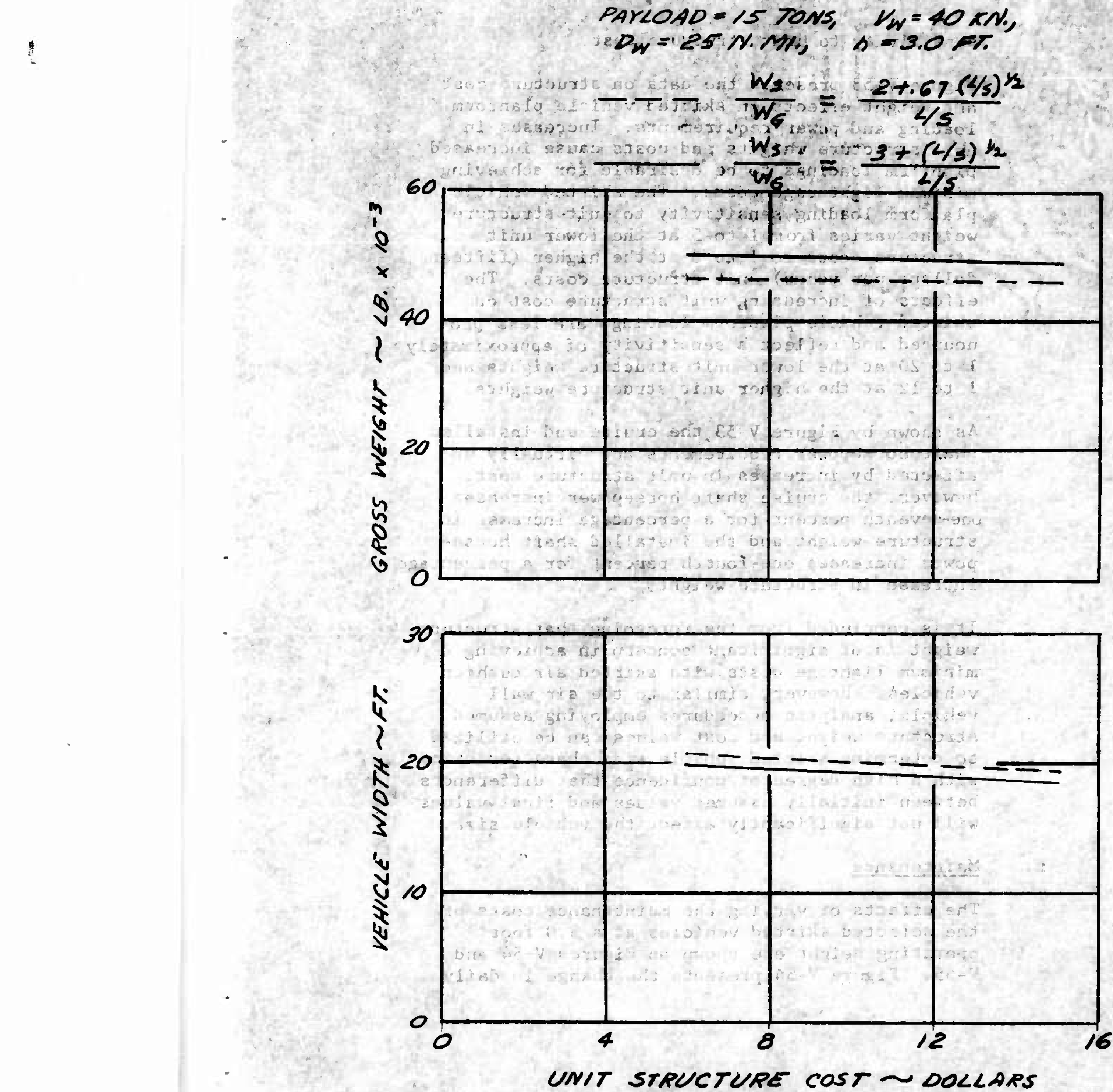


Figure V-52. Effect of Structure Weight and Cost on Skirted Air Cushion Vehicle Size.

sensitivity to unit structure cost.

Figure V-53 presents the data on structure cost and weight effects on skirted vehicle planform loading and power requirements. Increases in unit structure weights and costs cause increased planform loadings to be desirable for achieving minimum lighterage costs. The skirted vehicle planform loading sensitivity to unit structure weight varies from 1 to 5 at the lower unit structure costs to 1 to 3 at the higher (fifteen dollars per pound) unit structure costs. The effects of increasing unit structure cost on skirted vehicle planform loadings are less pronounced and reflect a sensitivity of approximately 1 to 20 at the lower unit structure weights and 1 to 12 at the higher unit structure weights.

As shown by Figure V-53, the cruise and installed shaft horsepower requirements are virtually unaffected by increases in unit structure cost. However, the cruise shaft horsepower increases one-seventh percent for a percentage increase in structure weight and the installed shaft horsepower increases one-fourth percent for a percentage increase in structure weight.

It is concluded from the foregoing that structure weight is of significant concern in achieving minimum lightage costs with skirted air cushion vehicles. However, similar to the air wall vehicle, analytic procedures employing assumed structure weight and cost values can be utilized to determine skirted vehicle size characteristics with a high degree of confidence that differences between initially assumed values and final values will not significantly affect the vehicle size.

f. Maintenance

The effects of varying the maintenance costs of the selected skirted vehicles at a 3.0 foot operating height are shown on Figures V-54 and V-55. Figure V-54 presents the change in daily

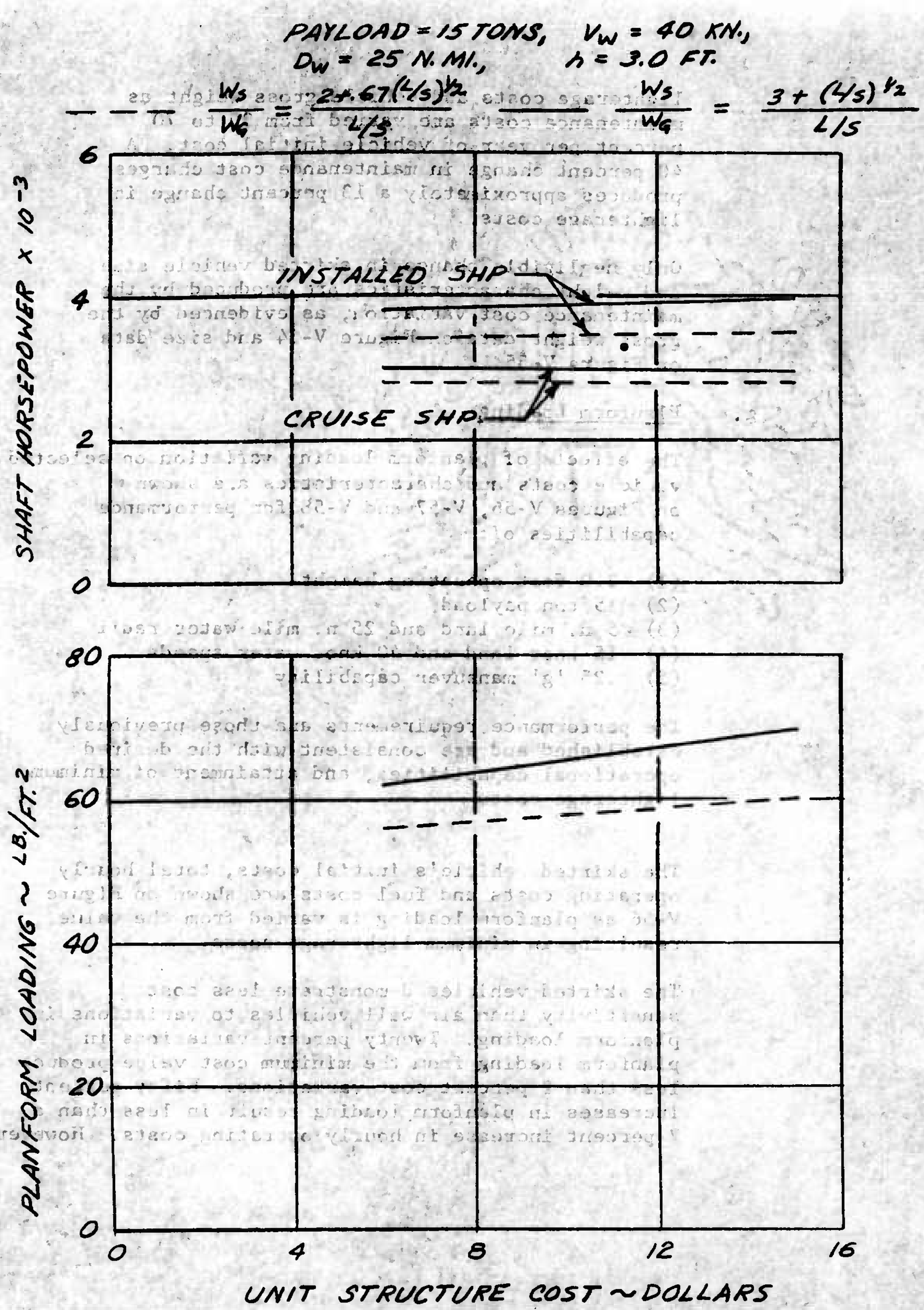


Figure V-53. Effect of Structure Weight and Cost on Skirted Air Cushion Vehicle Size and Power.

lighterage costs and vehicle gross weight as maintenance costs are varied from 30 to 70 percent per year of vehicle initial cost. A 40 percent change in maintenance cost charges produces approximately a 13 percent change in lighterage costs.

Only negligible change in skirted vehicle size and weight characteristics are produced by the maintenance cost variation, as evidenced by the gross weight data on Figure V-54 and size data on Figure V-55.

g. Planform Loading

The effects of planform loading variation on selected vehicle costs and characteristics are shown on Figures V-56, V-57 and V-58 for performance capabilities of:

(1) 3.0 foot operating height
(2) 15 ton payload
(3) 5 n. mile land and 25 n. mile water radii
(4) 15 knot land and 40 knot water speeds
(5) .25 'g' maneuver capability

The performance requirements are those previously established and are consistent with the desired operational capabilities, and attainment of minimum lighterage costs.

The skirted vehicle's initial costs, total hourly operating costs and fuel costs are shown on Figure V-56 as planform loading is varied from the value resulting in minimum lighterage costs.

The skirted vehicles demonstrate less cost sensitivity than air wall vehicles to variations in planform loading. Twenty percent variations in planform loading from the minimum cost value produce less than 2 percent cost variations. Fifty percent increases in planform loading result in less than a 7 percent increase in hourly operating costs. However,

PAYLOAD = 15 TON, D_W = 25 N.MI., V_W = 40 KN.
D_L = 5 N. MI., V_L = 15 KN.
h = 3.0 FT.
OPERATING HEIGHT = 3.0 FT.

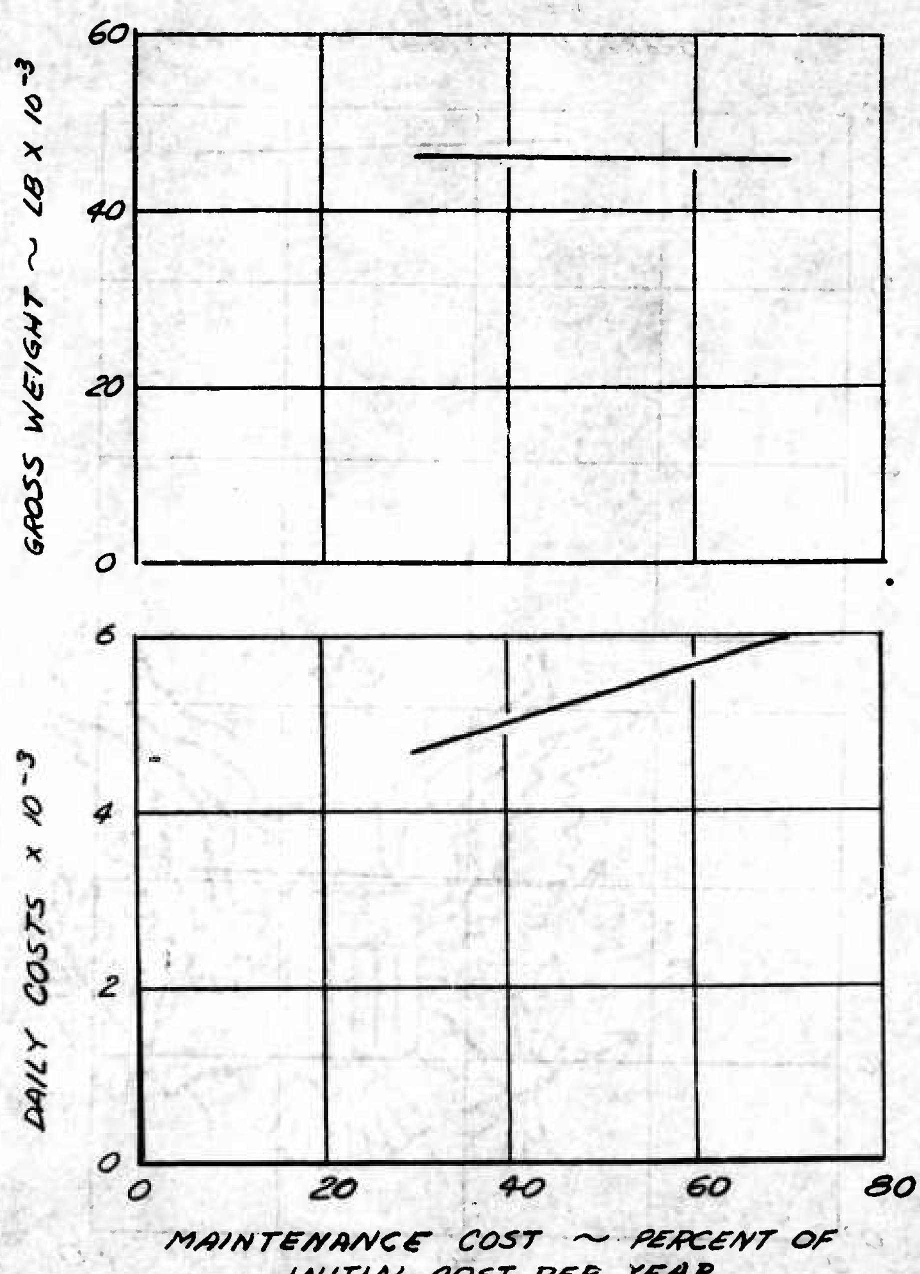


Figure V-54. Effect of Maintenance Cost on Skirted Air Cushion Lighterage Vehicle.

EFFECT OF MAINTENANCE COST ON SKIRTED AIR CUSHION LIGHTERAGE VEHICLE

PAYLOAD = 15 TON, D_W = 25 N.MI., V_W = 40 KN.
D_L = 5 N.MI., V_L = 15 KN.
h = 3.0 FT.
OPERATING HEIGHT = 3.0 FEET

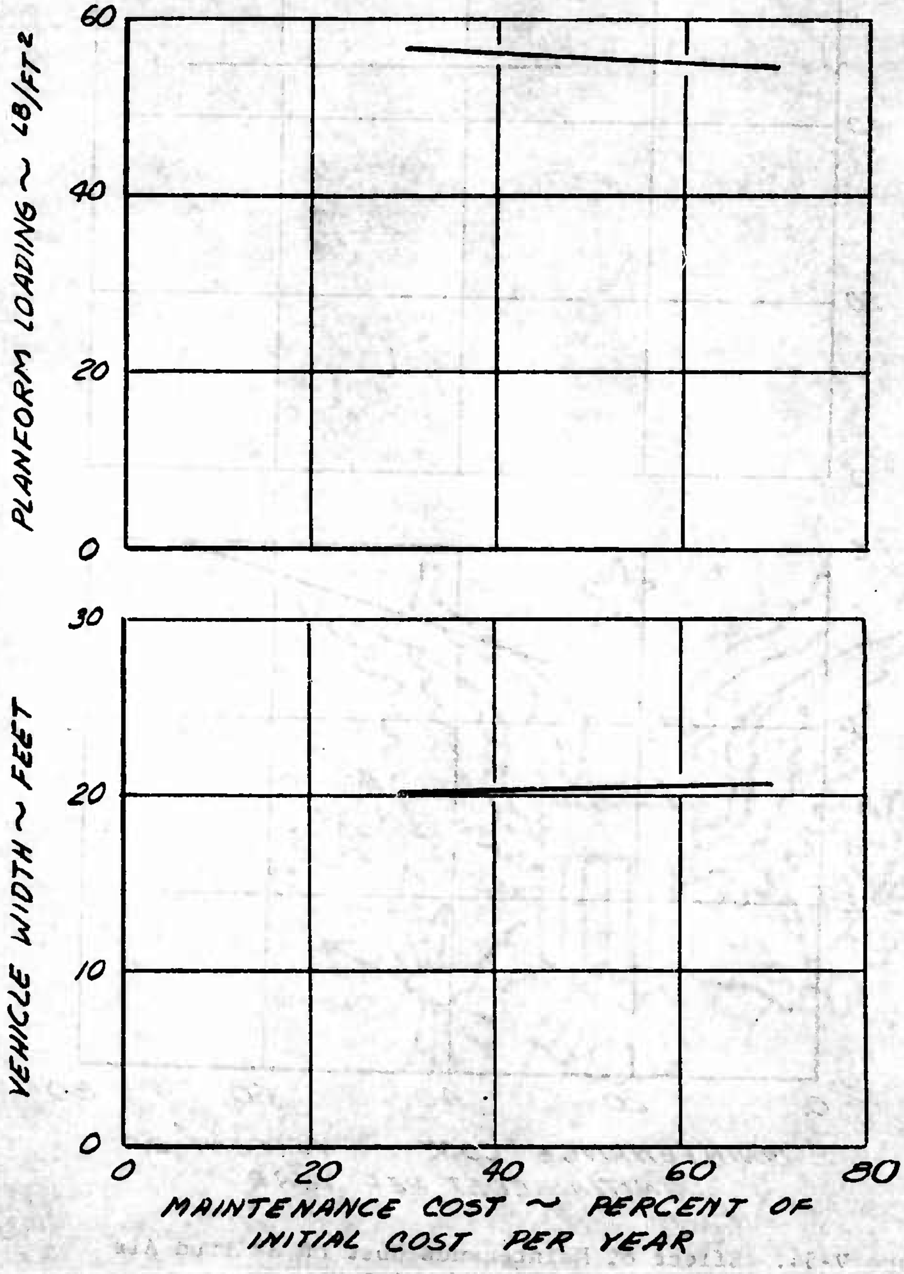


Figure V-55

reductions in planform loading by 50 percent would result in significant increases in costs.

The variation of skirted vehicle gross weight and width are shown on Figure V-57 as a function of planform loading. Skirted vehicle gross weight remains almost unchanged as planform loading is increased above the minimum cost value. Vehicle width reductions associated with planform loading increases are significant and caution must be exercised that the planform loading selected provides sufficient room for carrying the intended cargo. Conversely, small reductions in planform loadings can provide additional cargo space at nominal cost increases.

The variation of skirted vehicle power requirements for cruise and for lift plus maneuver at cruise speed are presented on Figure V-58. The installed power is the greater of the values shown.

The skirted vehicle power requirements are sensitive to planform loading, and reduction in installed power requirements could be obtained by lowering the planform loading below the value resulting in minimum lighterage costs. However, increased operating and fuel costs would result, in addition to an increase in vehicle gross weight and size.

The effects of planform loading on skirted vehicle characteristics and costs are similar to those obtained for air wall vehicles. However, the fully skirted vehicles are less sensitive than the air wall types to variations in planform loading.

The analytic procedures used for determining skirted vehicle characteristics having minimum cost also produce a vehicle which closely approximates minimum gross weight, minimum power requirements and minimum fuel requirements. Procedures which seek to minimize either gross weight or power requirements are apt to produce a vehicle which reflects daily lighterage costs approximately 5 percent greater than those obtained.

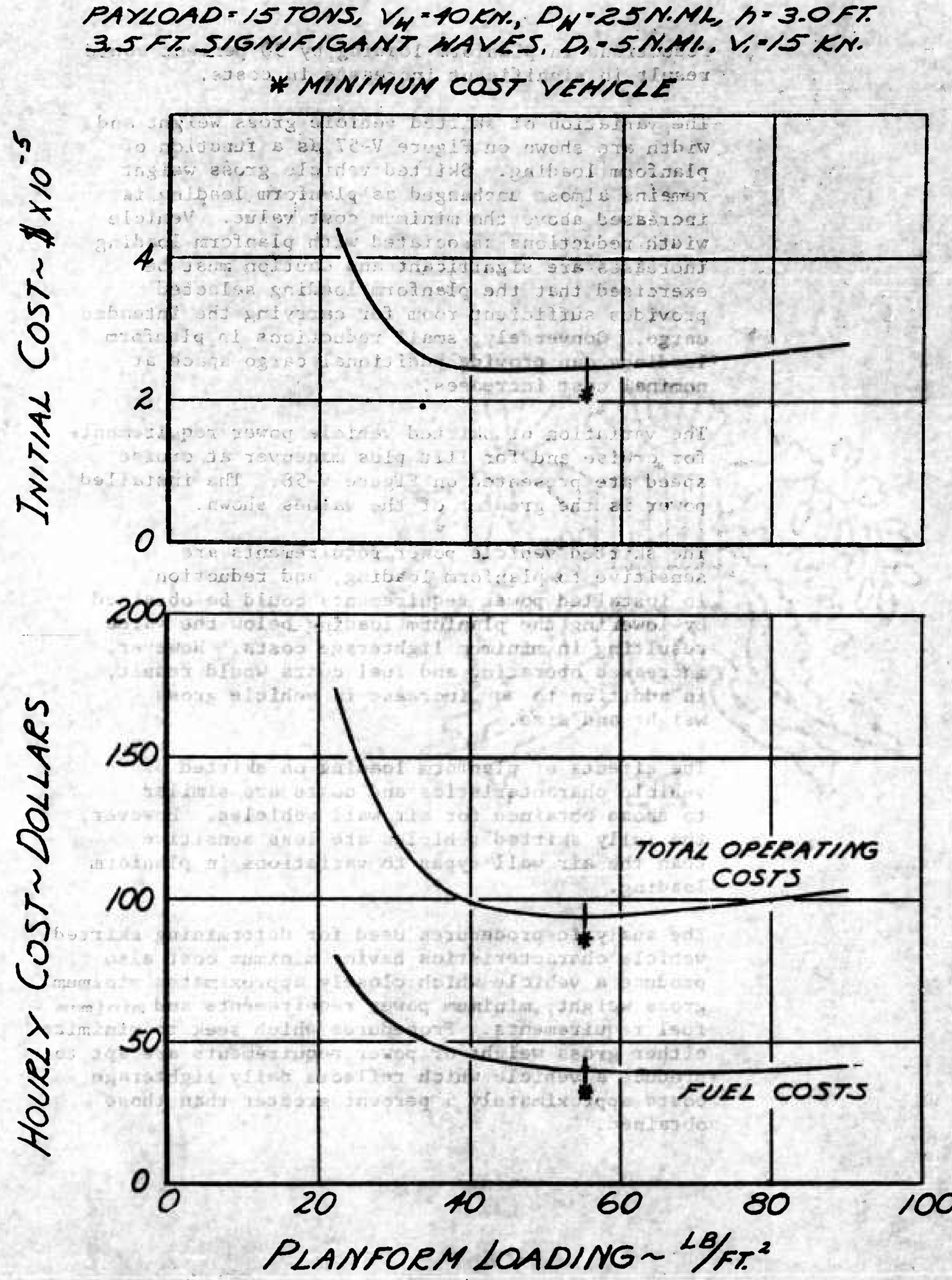


Figure V-56. Effect of Planform Loading on Skirted Air Cushion Vehicle Costs.

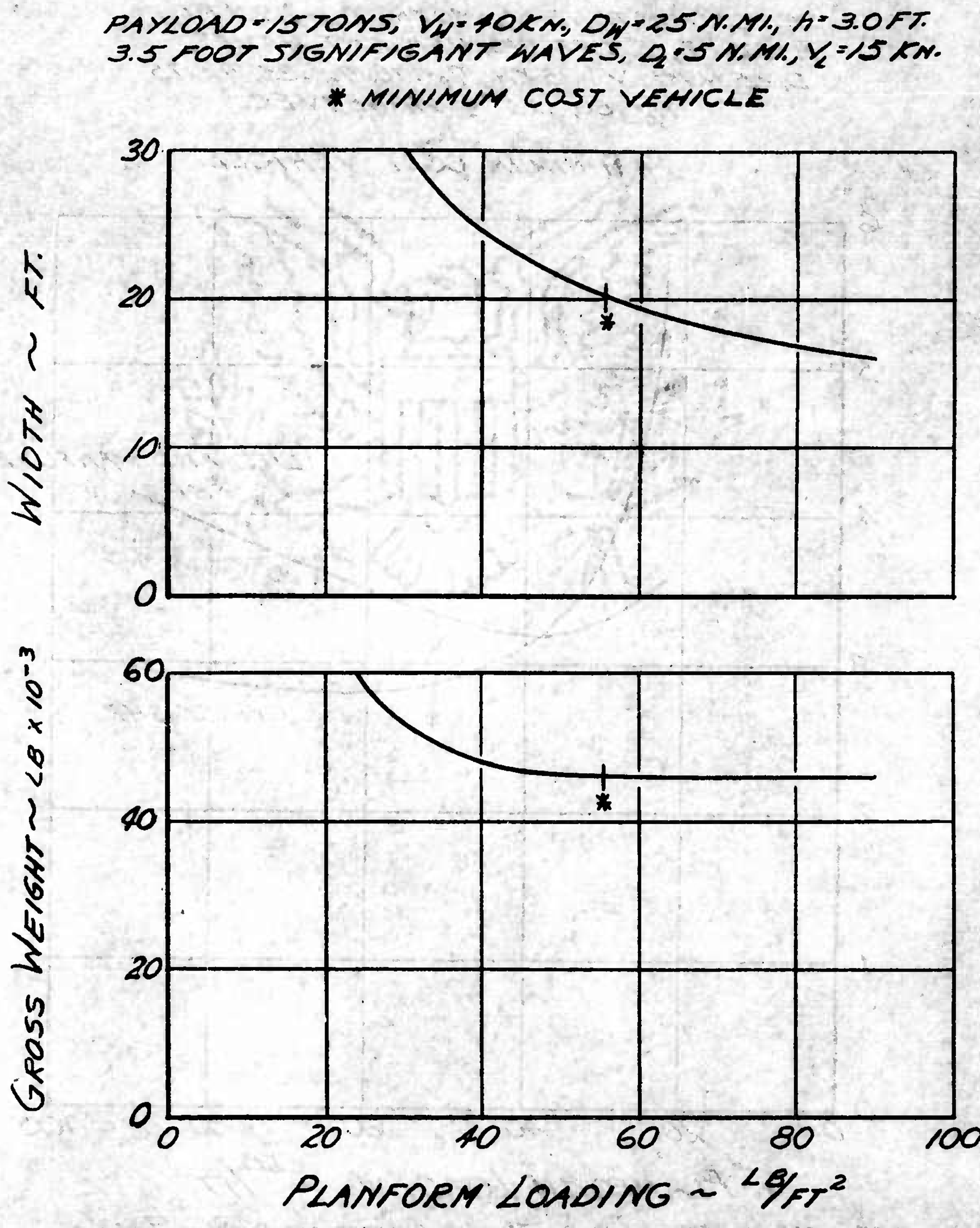


Figure V-57. Effect of Planform Loading on Skirted Air Cushion Vehicle Size.

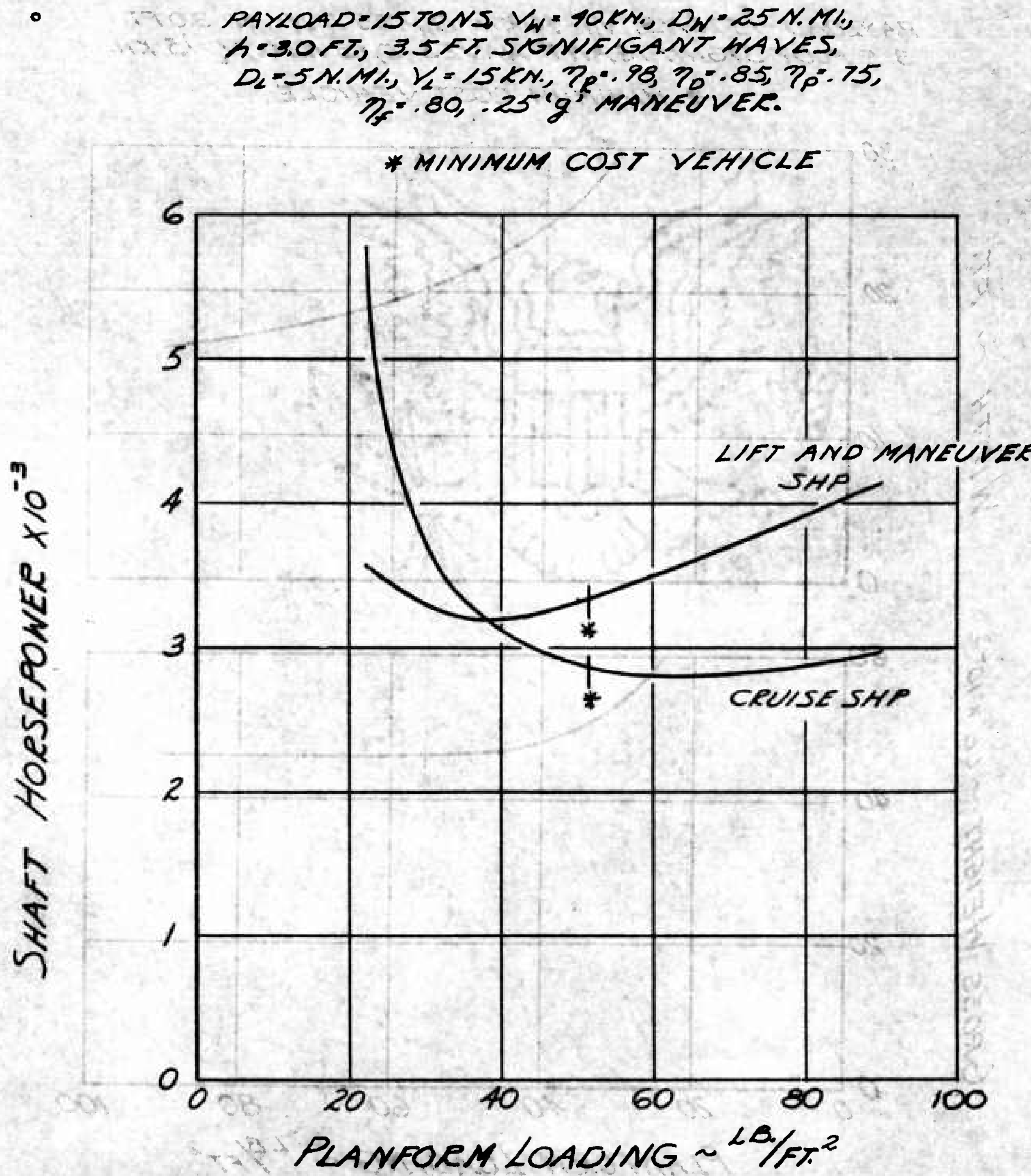


Figure V-58. Effect of Planform Loading on Skirted Air Cushion Vehicle Shaft Horsepower Requirements.

h. **Payload-Height Relationships**

The payload-height relationship of the 15 ton payload skirted vehicle designed to a 3.0 foot operating height is presented on Figure V-59. The payload versus operating height shown is consistent with the operating height versus significant wave height relationship on Figure V-1 and permits operating in such seas with an average wave impact frequency of 1 in 100 waves.

A reduction in operating height to one and one-half feet is accomplished by partial retraction of the flexible skirting and permits a payload approximating 40 tons to be carried in seas characterized by 1.8 feet high significant waves. Significant economic savings can, therefore, be obtained with the fully skirted vehicle when environment permits. The favorable environment payload capacities of the skirted vehicle provide for the transport of all Army equipments except for tanks, tank retrievers and heaviest self-propelled guns.

An increase in operating height to 4.7 feet (no payload condition) is accompanied by an extension of the flexible skirts and permits full speed operation in seas characterized by 5.4 foot significant waves. The skirted vehicle, therefore, falls short of meeting the desired goal of maintaining a useful payload in the highest seas in which ship unloading is assumed possible. It should be noted, however, that the ship's unloading rate will probably have degraded to slightly more than one-half the calm sea hatch rate when 5.4 significant waves are present (see Figure III-16).

i. **Hatch Rate Effects**

The effects of varying the hatch rate and accompanying unloading rate on lighterage costs of fully skirted vehicles are shown on Figure V-60.

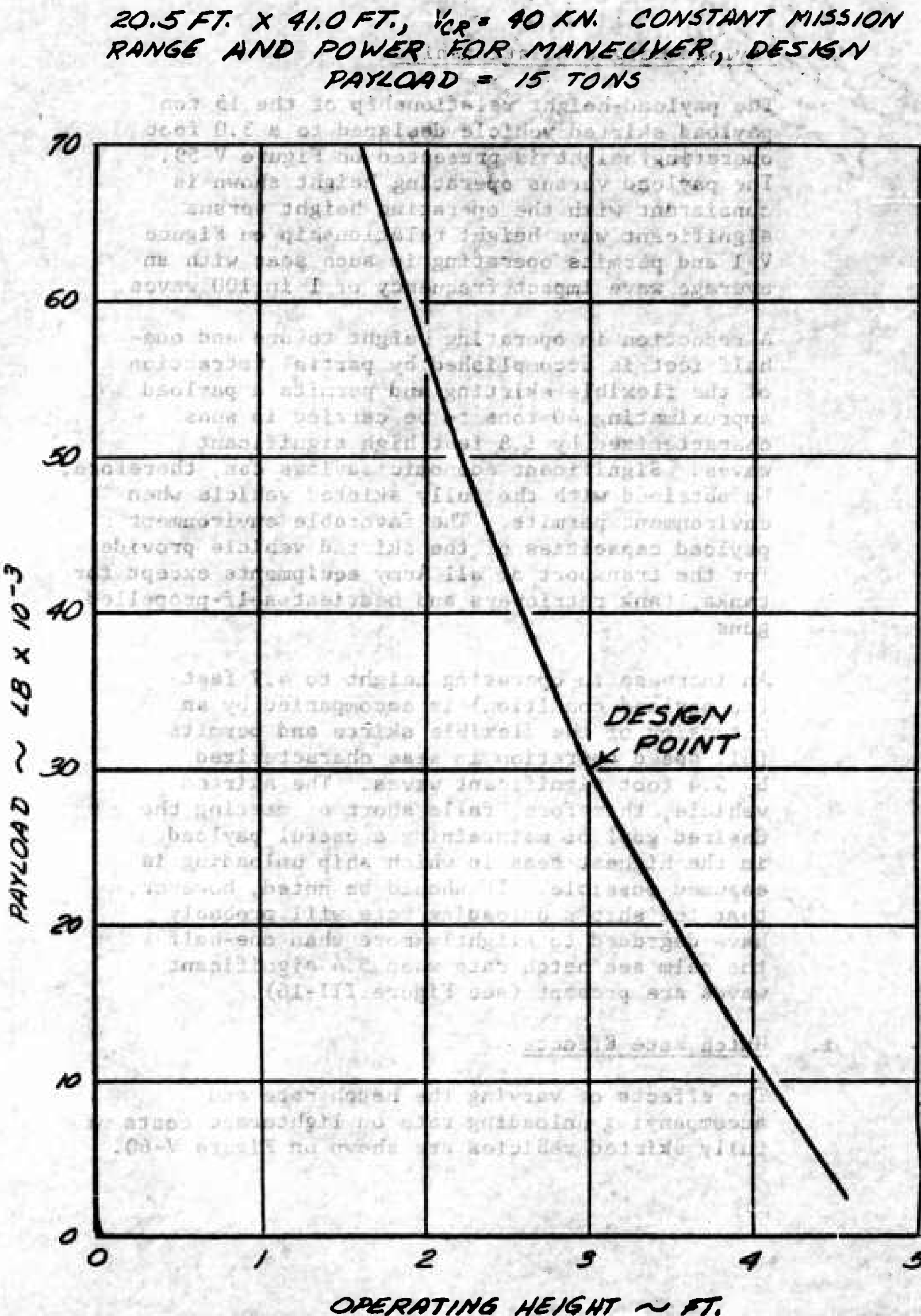


Figure V-59. Payload-Height Characteristics of Skirted Air Cushion Vehicle.

The cost trends evidenced by the skirted vehicles and the trends of payloads resulting in the most economical lighterage operation are similar to those shown by air wall vehicles.

The 15 ton payload skirted vehicle is economically superior at the 15 ton per hour hatch rate, while a 10 ton payload vehicle results in the most economic operation at a 7.5 ton per hour hatch rate and a 25 ton payload vehicle results in greater economy at a 30 ton per hour hatch rate.

Using the 15 ton per hour hatch rate as a base of reference, a 50 percent reduction in hatch rate (to 7.5 tons per hour) produces a 21 percent increase in lighterage cost. Additionally, a 10 ton payload vehicle provides the most economical lighterage operation at the reduced hatch rate. An increase in hatch rate by 50 percent (to 22.5 tons per hour) results in approximately a 9 percent reduction in lighterage costs and requires use of a 25 ton payload vehicle to obtain most economical lighterage operation.

As previously stated, it is important to provide cargo handling rates in excess of the currently accepted 7.2 tons per hour to fully realize the economic potential of air cushion vehicle lighterage. Additionally, it should be recognized that all lighterage suffer adverse cost effects at low hatch rates (shown later in Section VII).

3. PARTIALLY SKIRTED AIR CUSHION VEHICLES

Investigations of peripheral jet type partially skirted vehicles are inherently included in the analysis of air wall vehicles.

The exit jets of air wall vehicles can be extended beneath the vehicle's hard structure by means of abrasion resisting flexible skirts which deflect from their normal position when experiencing impact with an obstacle. As shown in References 21 and 25, only

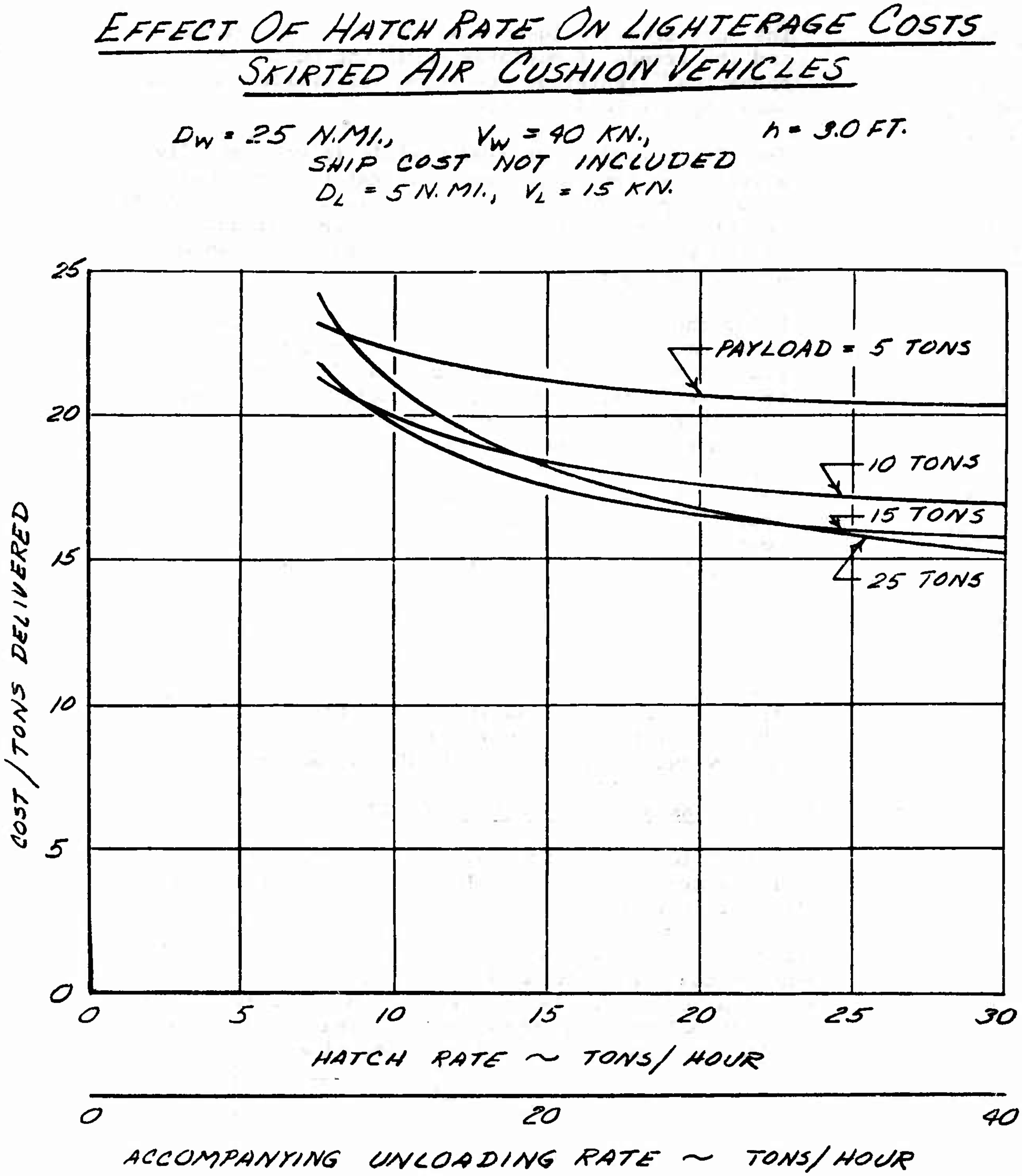

EFFECT OF HATCH RATE ON LIGHTERAGE COSTS
SKIRTED AIR CUSHION VEHICLES
D_W = 25 N.MI., V_W = 40 KN., h = 3.0 FT.
SHIP COST NOT INCLUDED
D_L = 5 N.MI., V_L = 15 KN.
PAYLOAD = 5 TONS
10 TONS
15 TONS
25 TONS
COST / TONS DELIVERED
0
5
10
15
20
25
0
5
10
15
20
25
30
HATCH RATE ~ TONS/HOUR
0
20
40
ACCOMPANYING UNLOADING RATE ~ TONS/HOUR

Figure V-60

external skirting of the jet is required to effectively extend the jet exit plane to the lower skirt edge.

Operation of a partially skirted air wall vehicle over wavy water has been previously discussed and is similar to that of an air wall vehicle with but one notable exception - skirt drag. Continuous skirt impact with the water will result in hydrodynamic drag in an amount proportional to the dynamic water pressure and skirt contact area and form.

The lack of engineering data on skirt characteristics precludes determination of the skirt length which results in the partially skirted air wall vehicle that exhibits maximum lighterage economy. An air wall vehicle incorporating a partial skirt one foot in length and having a three foot operating height was selected to illustrate operational capabilities consistent with the selected sea and terrain environmental criteria.

The partial flexible skirt of this vehicle will average no more than 1 wave impact out of every 10 waves encountered, and the vehicle's hard structure will impact with less than 1 out of every 100 waves during operation over seas characterized by 3.5 foot significant waves. Additionally, the low average wave impact frequency of the one foot long flexible skirt permits the logical assumption that hydrodynamic skirt drag can be neglected.

The previously presented performance, cost and vehicle characteristic data for air wall vehicles operating at 2.0 feet is, therefore, applicable to the air wall vehicle having an operating height of 3.0 feet and incorporating a one foot long flexible skirt.

Referring to the previously presented data on air wall vehicles, it can be shown that incorporation of the one foot long flexible skirt results in significant changes to the 10 ton payload air wall vehicle designed to:

(1) Three foot operating height

(2) Land radius of 5 nautical miles at 15 knots

(3) Water radius of 25 nautical miles at 80 knots

(4) Maneuver capability of .25 'g'

The significant cost and characteristic data of the simple air wall vehicle and the partially skirted air wall vehicle are presented in Table V-2 along with the percentage change from the values of the simple air wall vehicle.

TABLE V-2
COMPARISON CHARACTERISTICS OF PARTIALLY SKIRTED AND SIMPLE AIR WALL VEHICLES

ITEM	SIMPLE AIR WALL 10 TON PAYLOAD	PARTIAL SKIRT AIR WALL 10 TON PAYLOAD	PERCENT CHANGE
Daily Cost	\$ 6,300	\$ 5,300	-19 %
Initial Cost	\$ 295,000	\$ 253,500	-14.3%
Hourly Cost	\$ 101	\$ 88	-12.9%
Fuel Cost/Fuel Flow	\$ 41.55/2070 lb/hr	\$32.90/1645 lb/hr	-20.8%
Gross Weight	40,500 lb	37,500 lb	- 7.4%
Planform Loading	17.6 lb/ft^2	19.6 lb/ft^2	13.5%
Width	35 ft	31.5 ft	- 9.7%
Installed Power	3,720 SHP	3,160 SHP	-15 %
Cruise Power	2,860 SHP	2,270 SHP	-20.8%

The selected partially skirted vehicle shows a significant improvement in the cost and important vehicle characteristics and indicates the potential benefits derived with only minimal skirting. Additional skirting of the lighterage air cushion vehicle, even though accompanied by some hydrodynamic skirt drag is probably warranted. Exact definition of the proper amount of skirting is dependent upon the skirt hydrodynamic drag characteristics and is recommended for additional experimental and analytic study.

a. Planform Loading

The effects of varying the planform loading on partially skirted air wall vehicles is presented on Figures V-61, V-62 and V-63 to provide sensitivity data not shown in the section on pure air wall vehicles. Data presented are for vehicles designed to carry a 10 ton payload in the selected mission and mission environment previously delineated.

Figure V-61 presents the effects on vehicle costs due to planform loading variations from the value resulting in the minimum lighterage cost vehicle. A 50 percent increase in planform loading produces approximately a 14 percent increase in lighterage costs. Fuel costs increase approximately 24 percent, however.

The partially skirted air wall vehicles do not exhibit a significant change in gross weight with increasing planform loading as shown on Figure V-62. The gross weight reduces approximately 3 percent for a 50 percent increase in planform loading, which is similar in magnitude to that evidenced by pure air wall and fully skirted vehicles. The reduction in partially skirted vehicle width due to a 50 percent increase in planform loading approximates 22.5 percent, as one would expect.

The variation in partially skirted air cushion vehicle cruise and installed (lift plus maneuver) power requirements are shown as a function of planform loading on Figure V-63. A 50 percent planform loading increase results in approximately a 24 percent increase in cruise power requirements and a 20 percent increase in installed power requirements.

b. Payload Height Characteristics

The payload capabilities of the 10 ton payload partially skirted air wall vehicle at off-design operating heights are shown on Figure V-64. At a reduced operating height of 2.0 feet the payload capability of the partially skirted vehicle approximates 18 tons - slightly better than the pure air wall vehicle's 16 ton capacity at the same hard structure height. A 25 ton payload

EFFECT OF PLANFORM LOADING ON PARTIALLY SKIRTED AIR WALL AIR CUSHION VEHICLE COSTS

PAYLOAD = 10 TONS, V_W = 80 KN., D_W = 25 N.MI.,
h = 3.0 FT. WITH 1 FT. FLEX. SKIRT

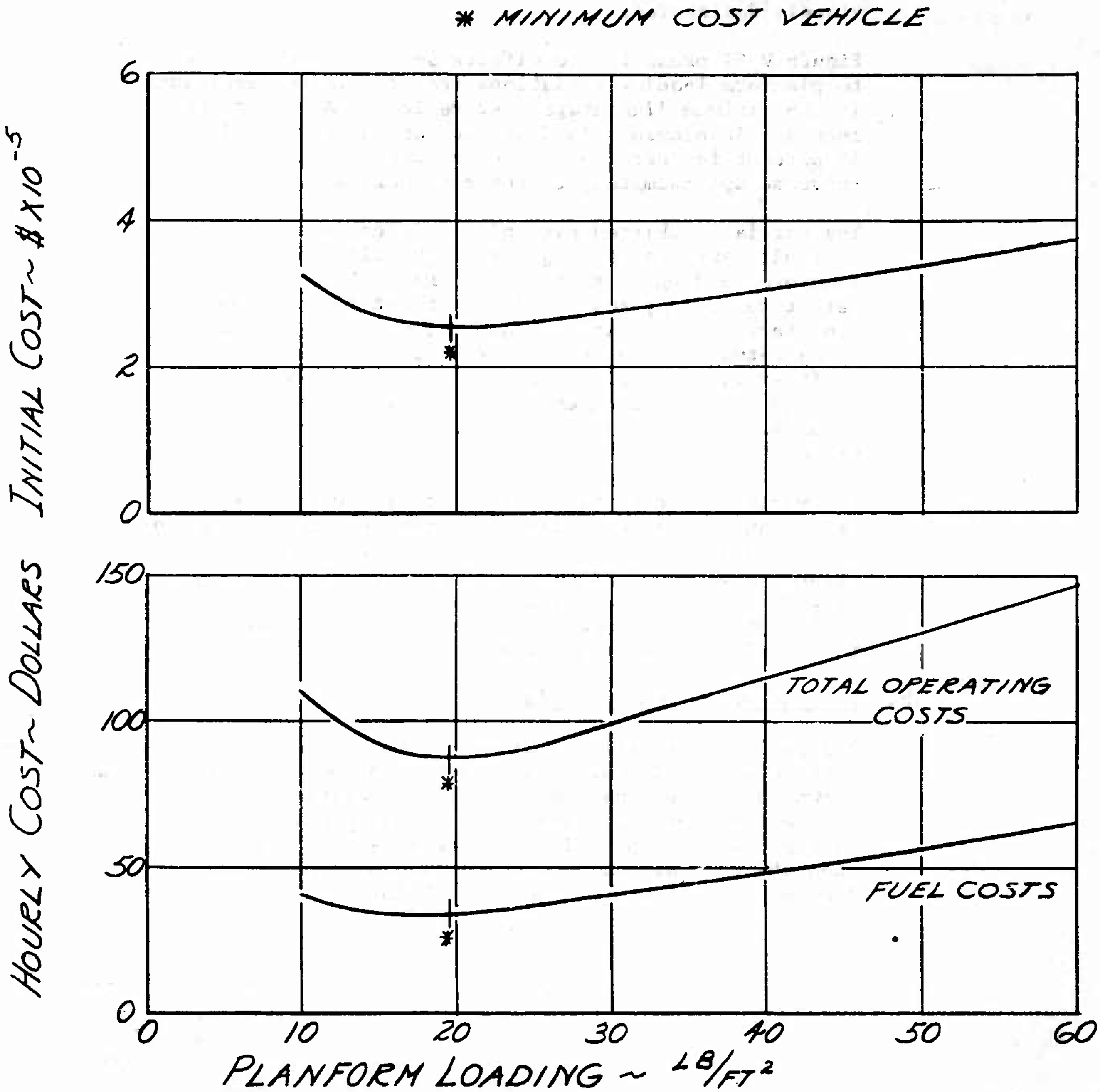


Figure V-61

EFFECT OF PLANFORM LOADING ON PARTIALLY SKIRTED AIR WALL AIR CUSHION VEHICLE SIZE

PAYLOAD = 10 TONS, V_W = 80 KN., D_W = 25 N.MI., h = 3.0 FT. WITH 1 FT. FLEX. SKIRT

* MINIMUM COST VEHICLE

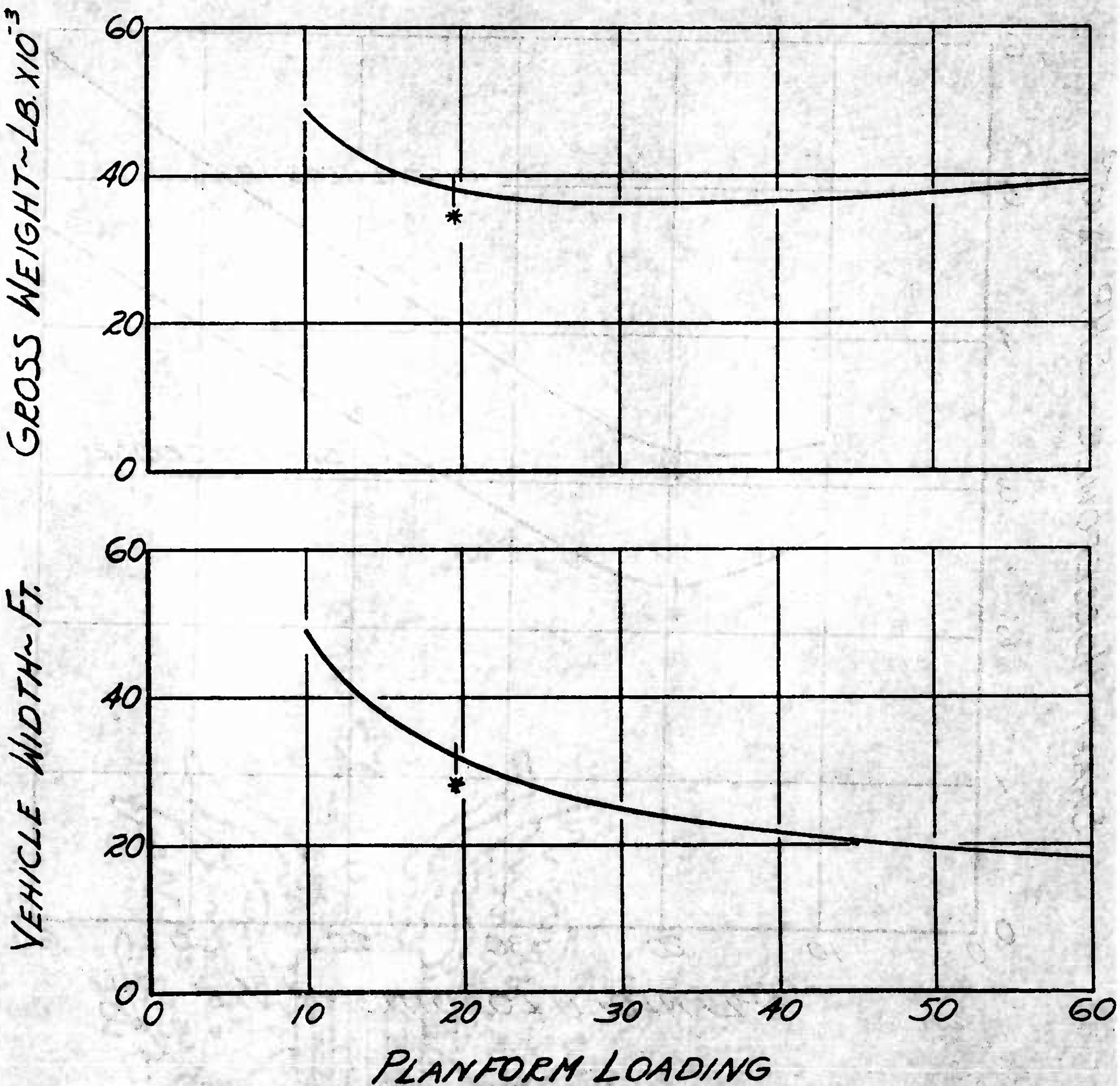


Figure V-62

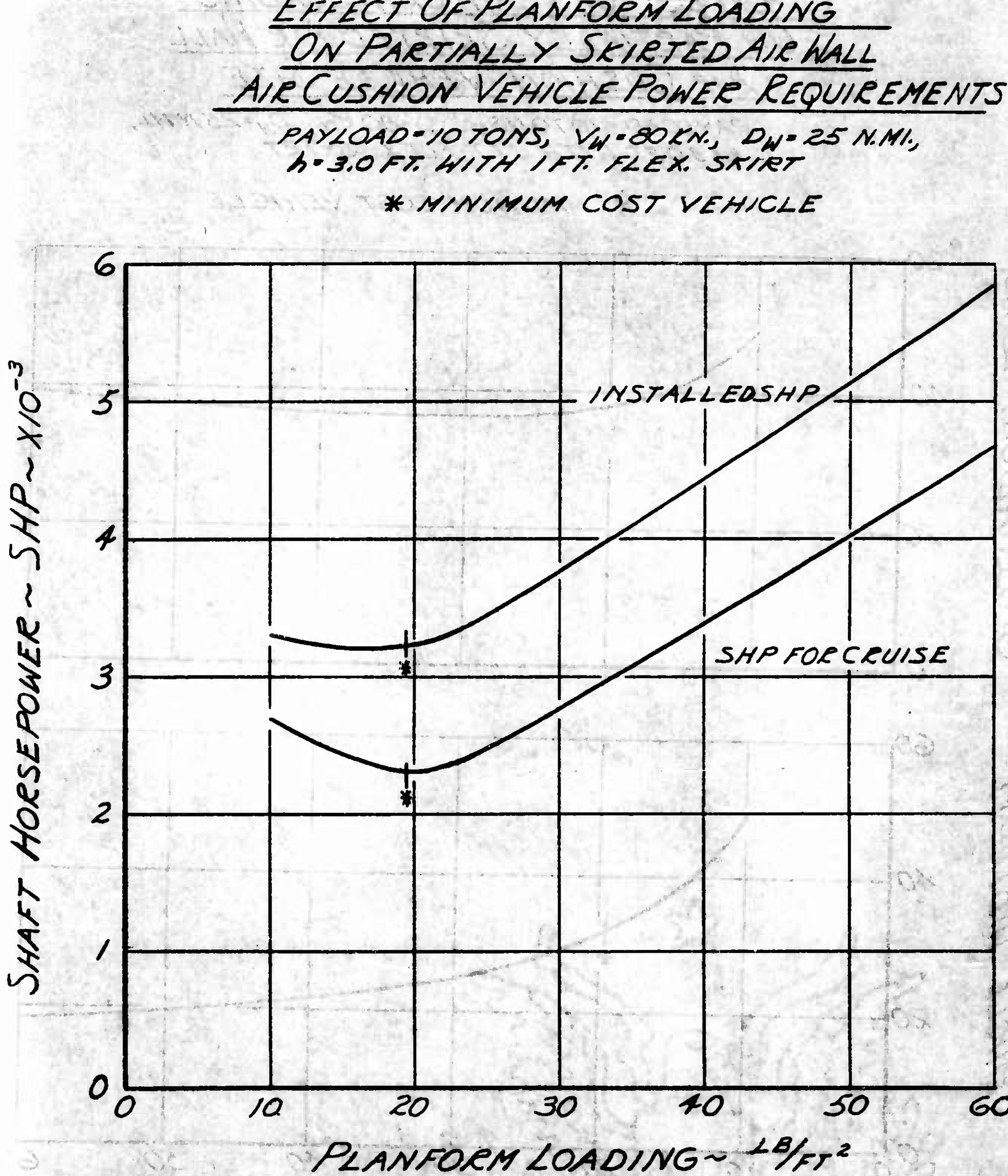

EFFECT OF PLANFORM LOADING
ON PARTIALLY SKIRTED AIR WALL
AIR CUSHION VEHICLE POWER REQUIREMENTS
PAYLOAD = 10 TONS, V_W = 80 KN., D_W = 25 N.MI.,
h = 3.0 FT. WITH 1 FT. FLEX. SKIRT
* MINIMUM COST VEHICLE
INSTALLED SHP
SHP FOR CRUISE
SHAFT HORSEPOWER ~ SHP ~ $\times 10^{-3}$
PLANFORM LOADING ~ LB/FT²
0
1
2
3
4
5
6
0
10
20
30
40
50
60

Figure V-63

Payload - Height Characteristics Air Wall Air Cushion Vehicle With 1 Foot Flexible Skirt

DESIGNED FOR 10 TON PAYLOAD, $h=3$ FT. $V_W=80$ KN, $D_W=25$ N.MI., $D_L=5$ N.MI., $V_L=15$ KN, t_c SIDE JET FIXED AT 0.7 FT., $\theta_j=15°$.

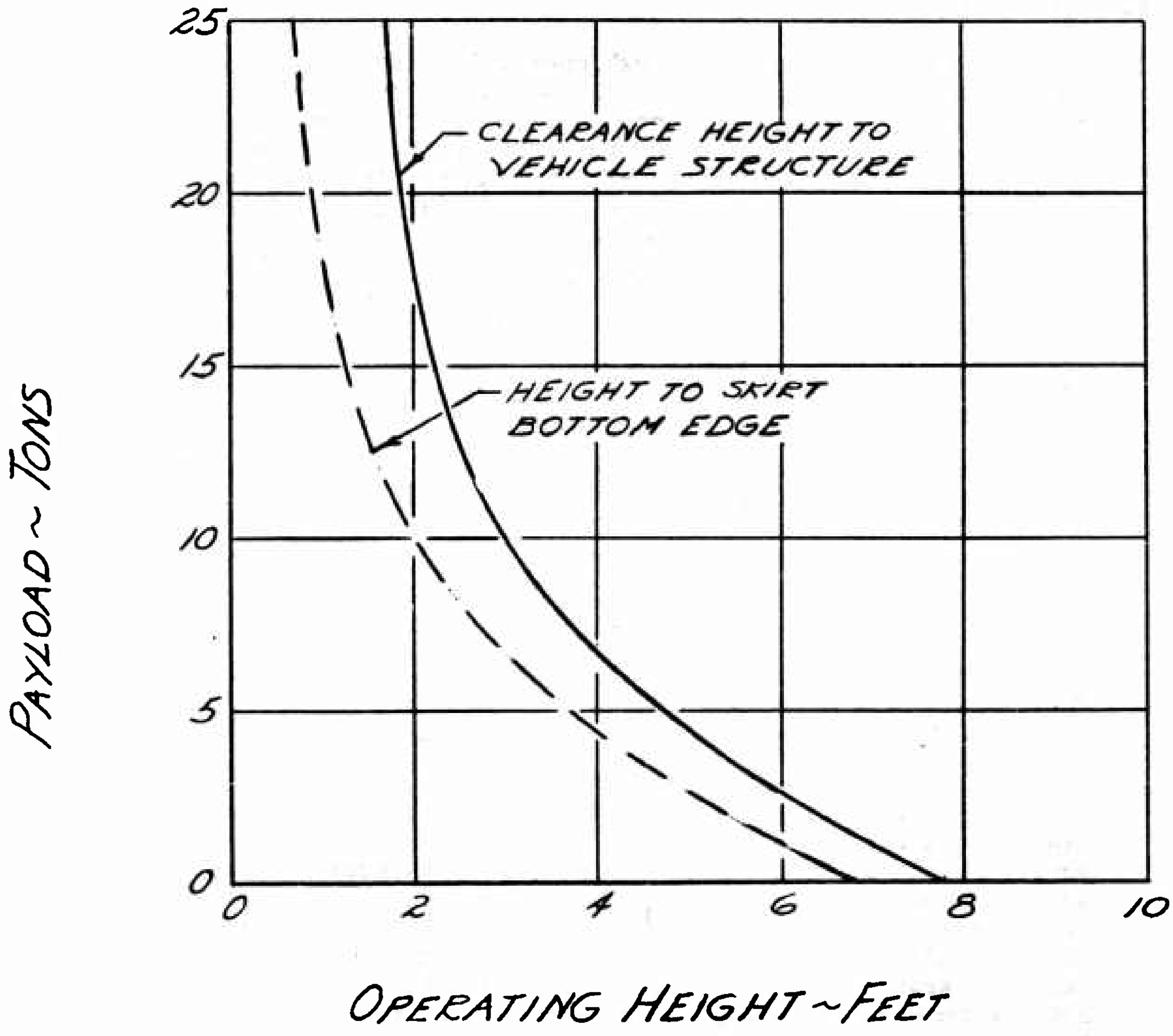


Figure V-64

capacity is evidenced by the partially skirted vehicle at an operating height of 1.8 feet. Additionally, the partially skirted vehicle has a payload capability of approximately 1.5 tons at an operating height of 6.3 feet, consistent with the highest seas in which ships are assumed capable of unloading cargo.

The partially skirted vehicle is, therefore, considered adequately capable of meeting the desired performance capabilities in adverse sea environments.

4. HYDROSKIMMER VEHICLES

As previously indicated, hydroskimmer vehicles can incorporate varying amounts of skirting on the bow and stern. The limiting case is a hydroskimmer with no jet flow from the skegs, and with transverse (bow and stern) skirts extending from hard base structure to the ground. This type vehicle was implicitly analyzed in the studies of fully skirted vehicles. At its 3.75 foot base height, necessary to clear all but one out of a hundred waves in seas with 3.5 foot significant waves, the limiting case vehicle has a payload of 15 tons, a water speed of 40 knots to provide a minimum daily lighterage cost of approximately 5300 dollars per day. Amphibious hydroskimmer vehicles with no transverse jet skirts and those with partial flexible skirts on transverse jets were derived for comparison purposes.

Investigations of hydroskimmer-type vehicles were limited to those vehicles optimized at a radius of operation of 5 nautical miles inland at 15 knots and 25 nautical miles over water. Additionally, the investigations were limited to investigation of over-water operation in seas characterized by 3.5 foot significant waves.

Three transverse jet heights were selected. The highest (4.5 feet) was selected to represent a vehicle whose base would contact significantly less than one in 100 waves in the design sea environment. The intermediate transverse jet height permits hard structure impact with an average of one out of 100 waves. The third transverse jet height is obtained by partial skirting of the transverse jets. The flexible skirts contact one out of ten waves in the stated sea environment, as do those of the partially skirted air wall vehicles and the base impacts an average of no more than one in hundred. The transverse jet heights and length of flexible skirts which meet the stated conditions of wave impact vary with the three different skeg heights used: 0 feet, 0.5 feet and 0.75 feet. The assumptions of hydroskimmer vehicle drag, skeg height above the wave trough and base height to skeg height relationship have been previously discussed in Section V-D.

The variation of transverse jet heights with skeg operating heights are tabulated for the stated wave impact conditions and operation in seas with 3.5 foot significant waves.

Condition of Wave Impact	Skeg Height-Ft.	Transverse Jet Height-Ft.	Minimum Base Height-Ft.	Transverse Skirt Length-Ft.
Less than 1 in 100	0	4.5*	4.5*	0
	0.5	4.5*	4.5*	0
	0.75	4.5*	4.5*	0
Average of 1 in 100	0	3.71	3.71	0
	0.5	3.0	3.0	0
	0.75	2.85	2.85	0
Average of 1 in 10 with skirts	0	2.86	3.71	0.85
	0.5	2.15	3.0	0.85
	0.75	2.0	2.85	0.85

*Arbitrary height selection

The data on Figure V-65 for hydroskimmer vehicles with zero skeg height indicates that operation with partial flexible skirts on the transverse jets (transverse jet height = 2.86 ft. curve) provides minimum lighterage cost. An overwater speed of 40 knots and a payload of 15 tons provides minimum lighterage cost with these vehicles.

Figure V-66 presents lighterage cost data for hydroskimmer vehicles whose skegs operate clear of the smooth ground by .5 feet. The data again indicates that employment of transverse jet flexible skirts (transverse jet height = 2.15 feet curves) results in minimum lighterage costs at speeds of 40 knots and vehicle payloads of 15 tons.

The lighterage cost data for hydroskimmer vehicles employing skeg heights of .75 feet are presented on Figure V-67. Employing flexible skirts on the transverse jets (transverse jet height - 2.0 feet curves) again results in minimum lighterage cost with the vehicles operating at 40 knots overwater and carrying approximately a 15 ton payload.

Figure V-68 presents the variation of minimum lighterage costs of hydroskimmer vehicles as a function of their skeg height above ground and for three transverse jet heights permitting:

(1) wave impact of flexible skirts with 1 in 10 waves,

(2) wave impact of hard structures with no more than 1 in 100 waves,

(3) 4.5 feet height--less than 1 wave impact in every 100 waves.

HYDROSKIMMER AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 56% INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB/SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+.67(4/S)^.5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; ℓc/h = .35; MAXIMUM VEHICLE WIDTH = 35 FT.; SIGNIFICANT WAVE HEIGHT = 3.5 FT.; HEIGHT OF SIDE JET = .0 FT.

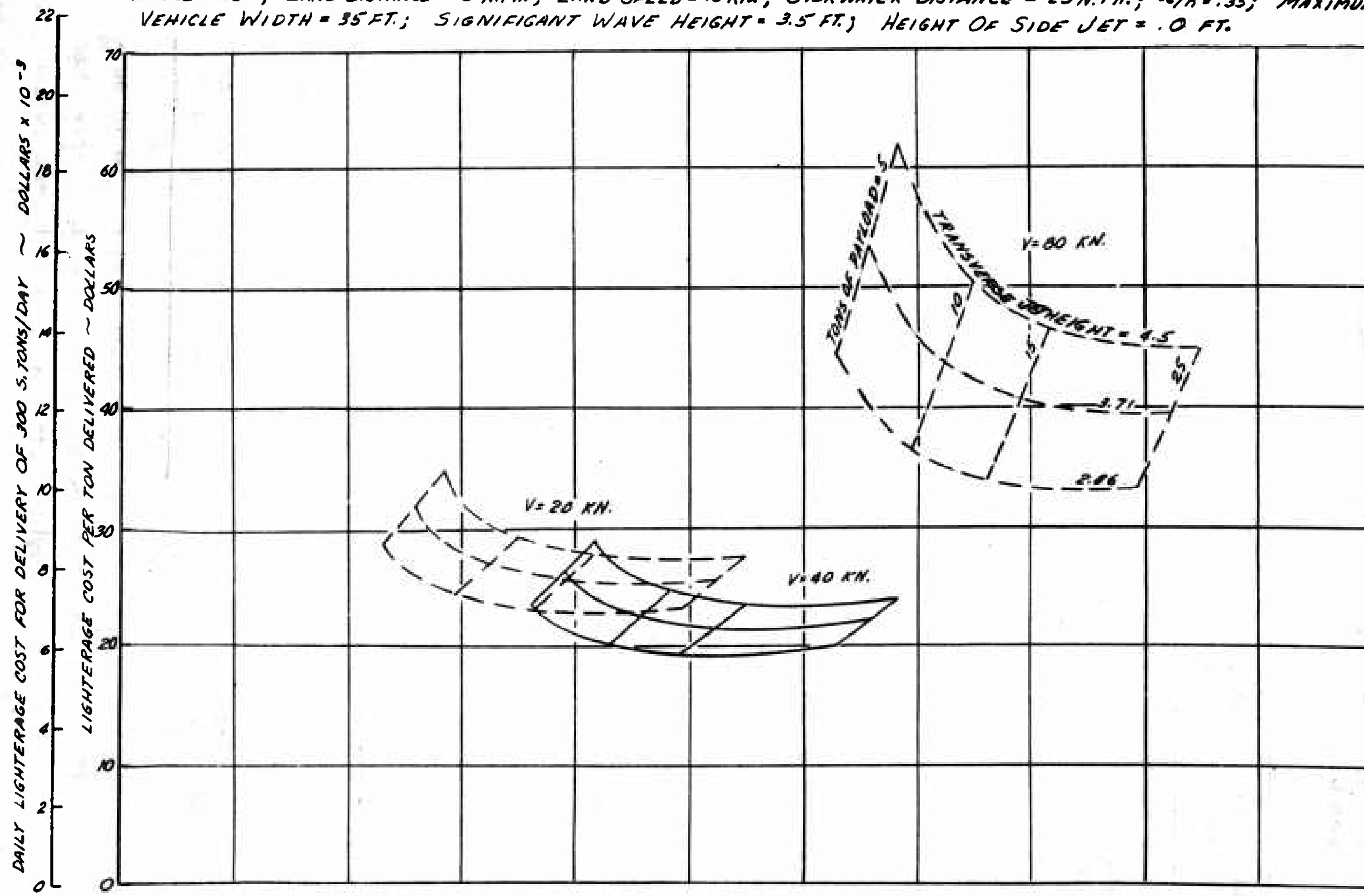


Figure V-65

HYDROSKIMMER AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 56% INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 14 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+.67(ℓ/s)·5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 g; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI. MAXIMUM VEHICLE WIDTH = 35 FT.; *SIGNIFICANT WAVE HEIGHT = 3.5 FT.; HEIGHT OF SIDE JET = .5 FT.

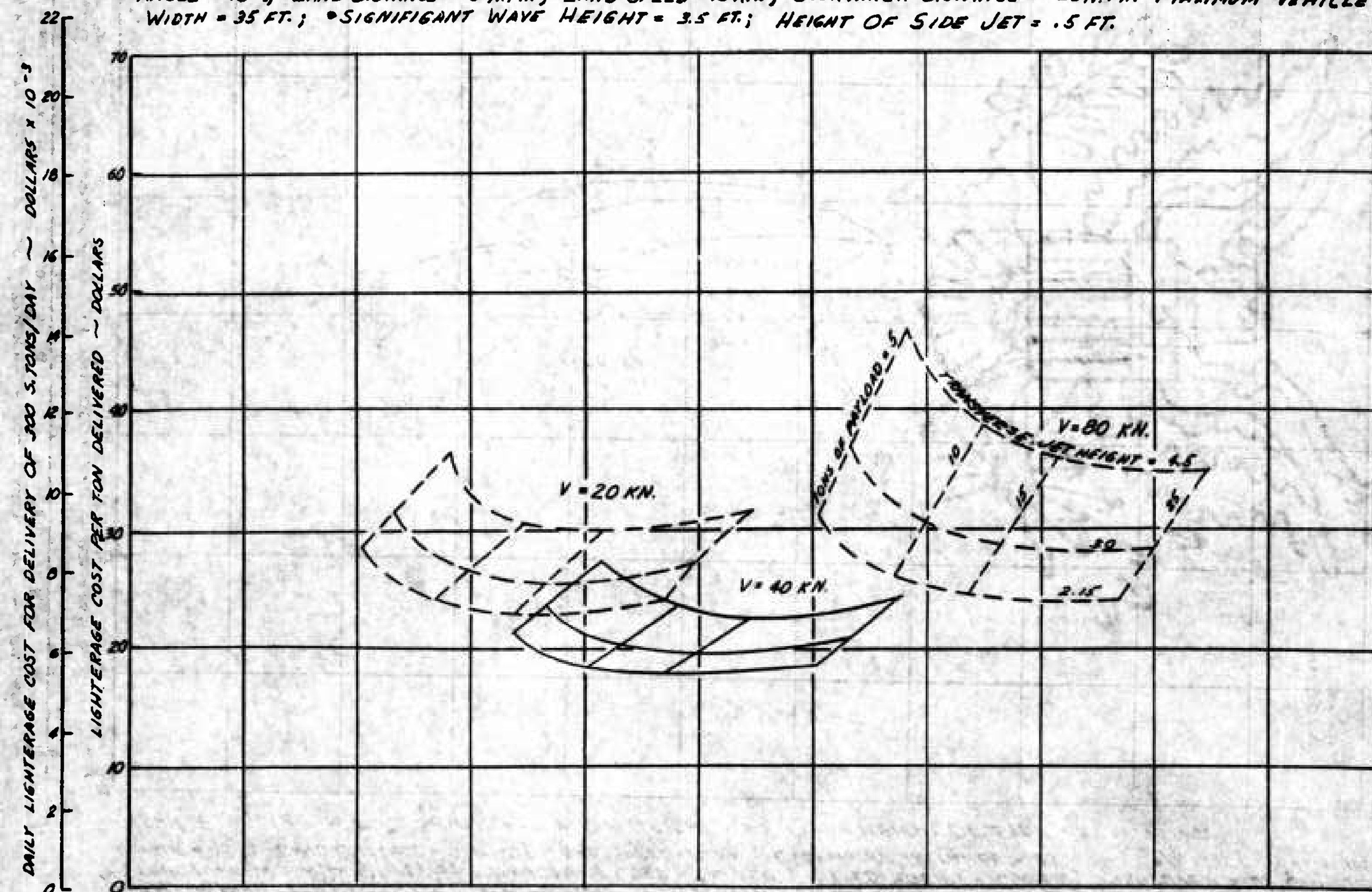


Figure V-66

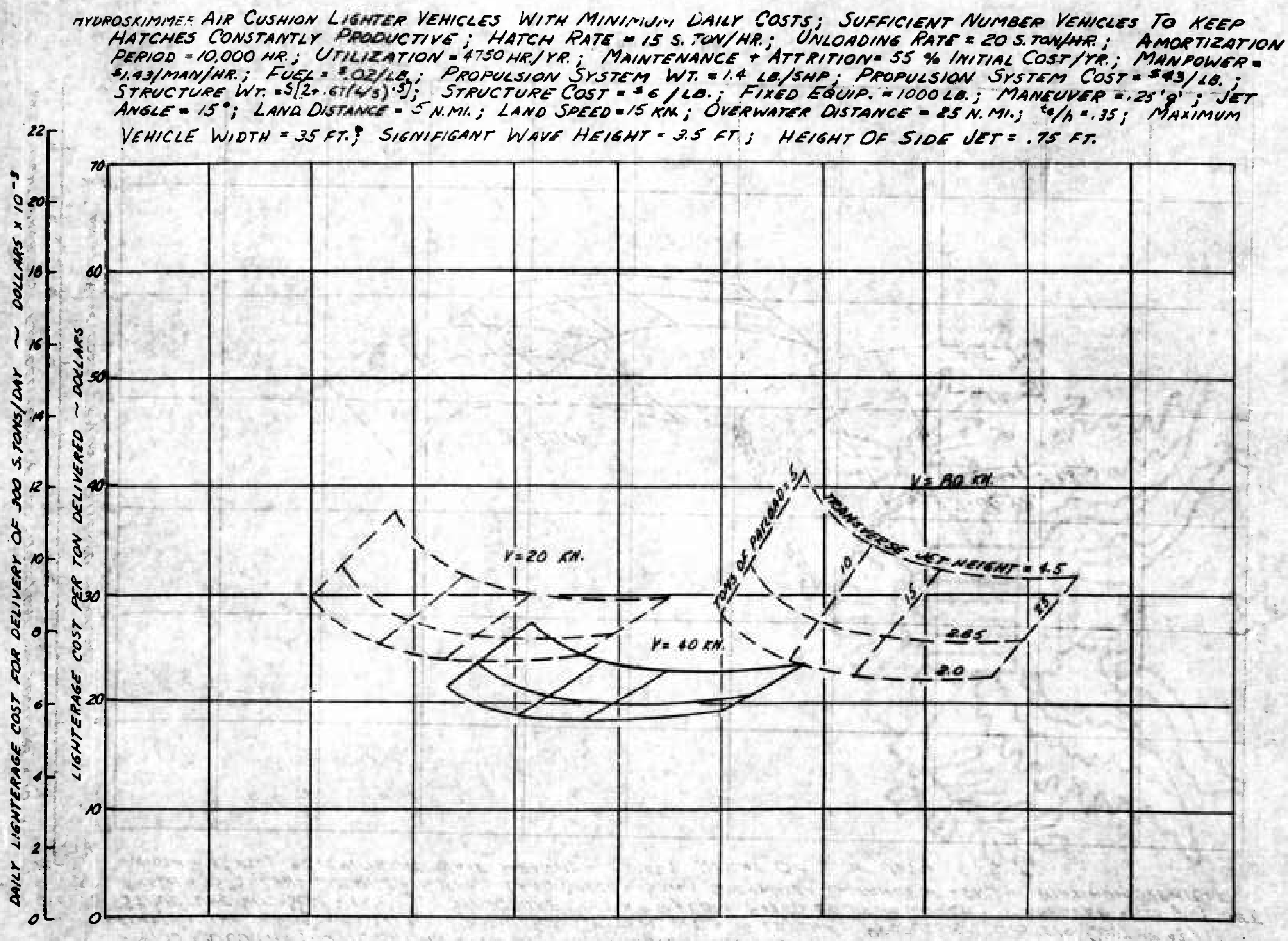

HYDROSKIMMER AIR CUSHION LIGHTER VEHICLES WITH MINIMUM DAILY COSTS; SUFFICIENT NUMBER VEHICLES TO KEEP HATCHES CONSTANTLY PRODUCTIVE; HATCH RATE = 15 S. TON/HR.; UNLOADING RATE = 20 S. TON/HR.; AMORTIZATION PERIOD = 10,000 HR.; UTILIZATION = 4750 HR./YR.; MAINTENANCE + ATTRITION = 55 % INITIAL COST/YR.; MANPOWER = $1.43/MAN/HR.; FUEL = $.02/LB.; PROPULSION SYSTEM WT. = 1.4 LB./SHP; PROPULSION SYSTEM COST = $43/LB.; STRUCTURE WT. = S[2+.67(4/S)·5]; STRUCTURE COST = $6/LB.; FIXED EQUIP. = 1000 LB.; MANEUVER = .25 'g'; JET ANGLE = 15°; LAND DISTANCE = 5 N.MI.; LAND SPEED = 15 KN.; OVERWATER DISTANCE = 25 N.MI.; t_e/h = .35; MAXIMUM VEHICLE WIDTH = 35 FT.; SIGNIFICANT WAVE HEIGHT = 3.5 FT.; HEIGHT OF SIDE JET = .75 FT.
DAILY LIGHTERAGE COST FOR DELIVERY OF 300 S.TONS/DAY ~ DOLLARS x 10^-3
LIGHTERAGE COST PER TON DELIVERED ~ DOLLARS
V=20 KN.
V=40 KN.
V=80 KN.
TONS OF PAYLOAD = 5
10
15
25
TRANSVERSE JET HEIGHT = 4.5
2.85
2.0
0
2
4
6
8
10
12
14
16
18
20
22
0
10
20
30
40
50
60
70

Figure V-67

HYDROSKIMMER VEHICLE LIGHTERAGE COSTS
SEAS CHARACTERIZED BY
3.5 FT. SIGNIFIGANT WAVES

PAYLOAD = 15 TONS, D_L = 5 N.MI., V_L = 15 KNOTS
D_W = 25 N.MI., V_W = 40 KN., SIDE JET t_e/h = .35
θ_J = 15°
.25 'g' MANEUVER

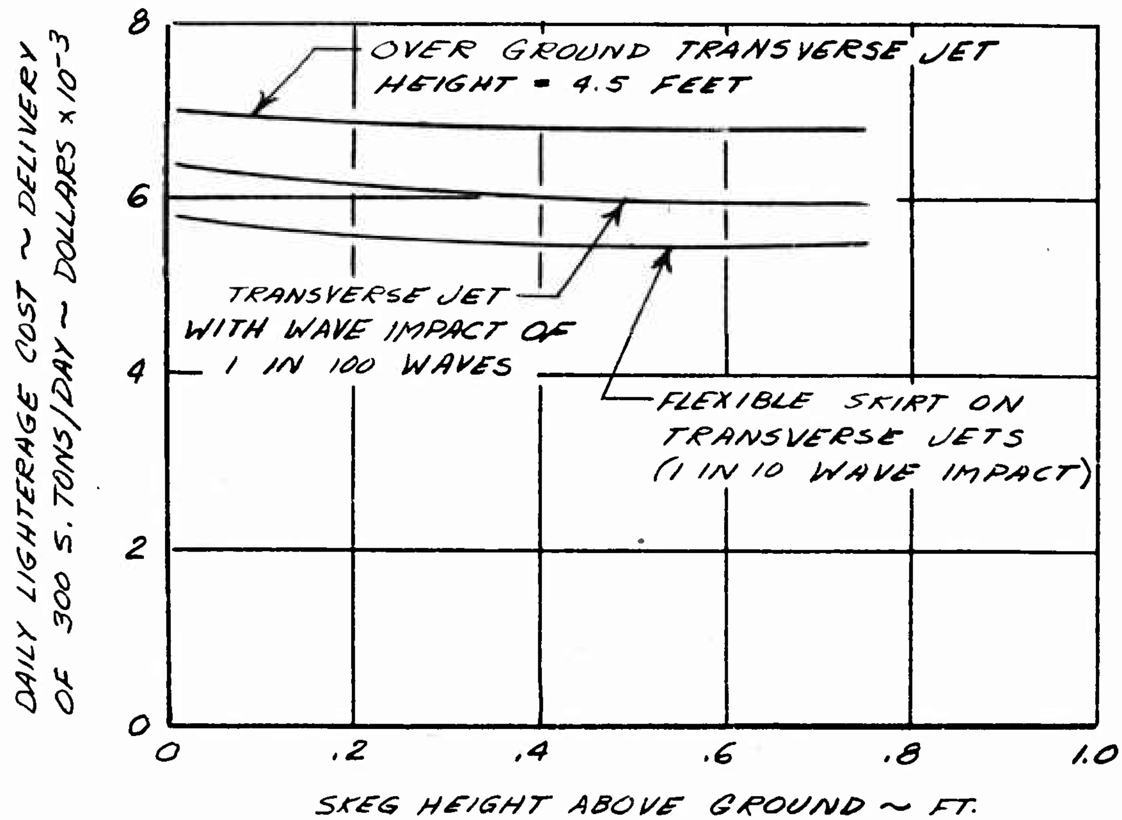


Figure V-68

Comparison of the data on Figure V-68 with lighterage cost data for fully skirted and partially skirted vehicles indicates the hydroskimmer vehicles are competitive with the other types. Unfortunately, the allocation of time and funds to this study preclude determining the appropriate combination of skeg length, flexible skirt length, etc., which could provide a three foot ground operating height upon retraction of the skegs. In light of the hydroskimmer vehicle's comparative economic standing with both fully skirted and partially skirted air cushion vehicles, it is the contractor's opinion that the mechanical and operational complexities associated with skeg retraction eliminates hydroskimmer vehicle use in LOTS operation. Hydroskimmer air cushion vehicles should, however, be considered for use in operations other than those requiring high overland operating heights.

The characteristics of minimum lighterage cost hydroskimmer vehicles having a 15 ton payload and 40 knot overwater speed are presented on Figures V-69 through V-74 for information purposes.

Calling attention to the values of vehicle characteristics corresponding to the lowest transverse jet operating height shown on the cited Figures (vehicles employing transverse jet flexible skirts), it is noticed that vehicle gross weight (approximately 50,000 pounts) and installed power (approximating 3,800 SHP) remain unchanged with increasing skeg operating height. The hydroskimmer vehicle's width increases with increasing skeg operating height from a low value of 28 feet at a skeg height of zero feet to a high of 33 feet at a skeg height of .75 feet.

The cruise power requirements of the partial skirted hydroskimmer vehicles diminish from a high value of 2,800 SHP at a skeg operating height of zero feet to a low of 2,000 SHP at a skeg operating height of .75 feet. The diminishing cruise power requirements reflect the assumed variation in hydrodynamic drag with increasing skeg height, which more than compensates for the increasing cruise lift power requirements.

The planform loadings of hydroskimmer vehicles with transverse jet flexible skirting decrease from a high of 33 pounds per square foot at zero feet to a low of 24 pounds per square foot at a skeg height of .75 feet.

In summary, the hydroskimmer vehicles are economically competitive in the selected LOTS mission with the other types of air cushion vehicles. However, the mechanical complexities associated with skeg retraction detracts from their possible application to LOTS operations. Additionally, the gross weights and installed power requirements of the minimum cost hydroskimmers remain unchanged with increasing skeg operating height, although the size of the vehicle increases noticeably.

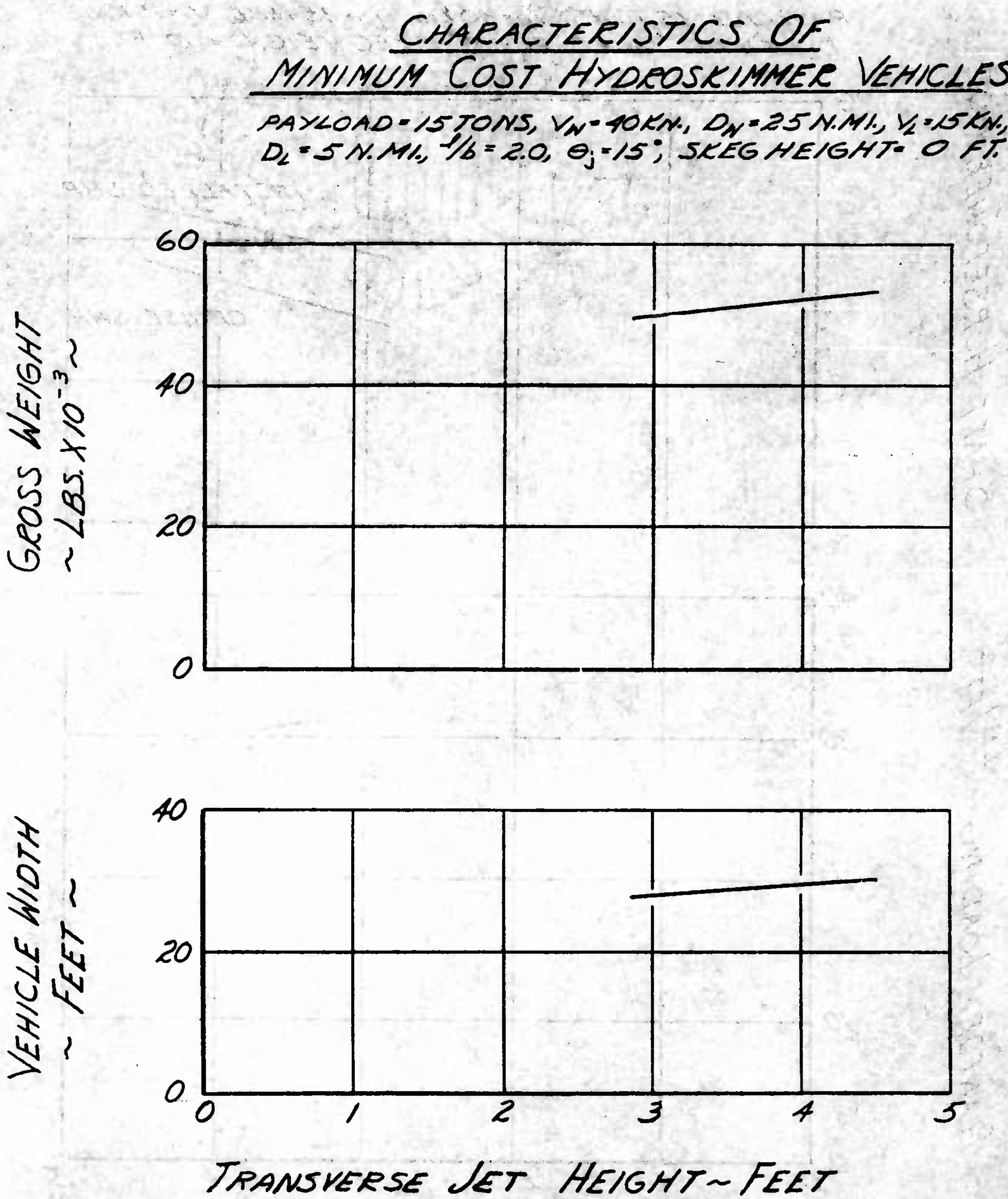

CHARACTERISTICS OF
MINIMUM COST HYDROSKIMMER VEHICLES
PAYLOAD = 15 TONS, V_N = 40 KN., D_N = 25 N.MI., V_L = 15 KN.,
D_L = 5 N.MI., l/b = 2.0, θ_j = 15°, SKEG HEIGHT = 0 FT.
GROSS WEIGHT
~ LBS. X 10^{-3} ~
60
40
20
0
VEHICLE WIDTH
~ FEET ~
40
20
0
0
1
2
3
4
5
TRANSVERSE JET HEIGHT ~ FEET

Figure V-69

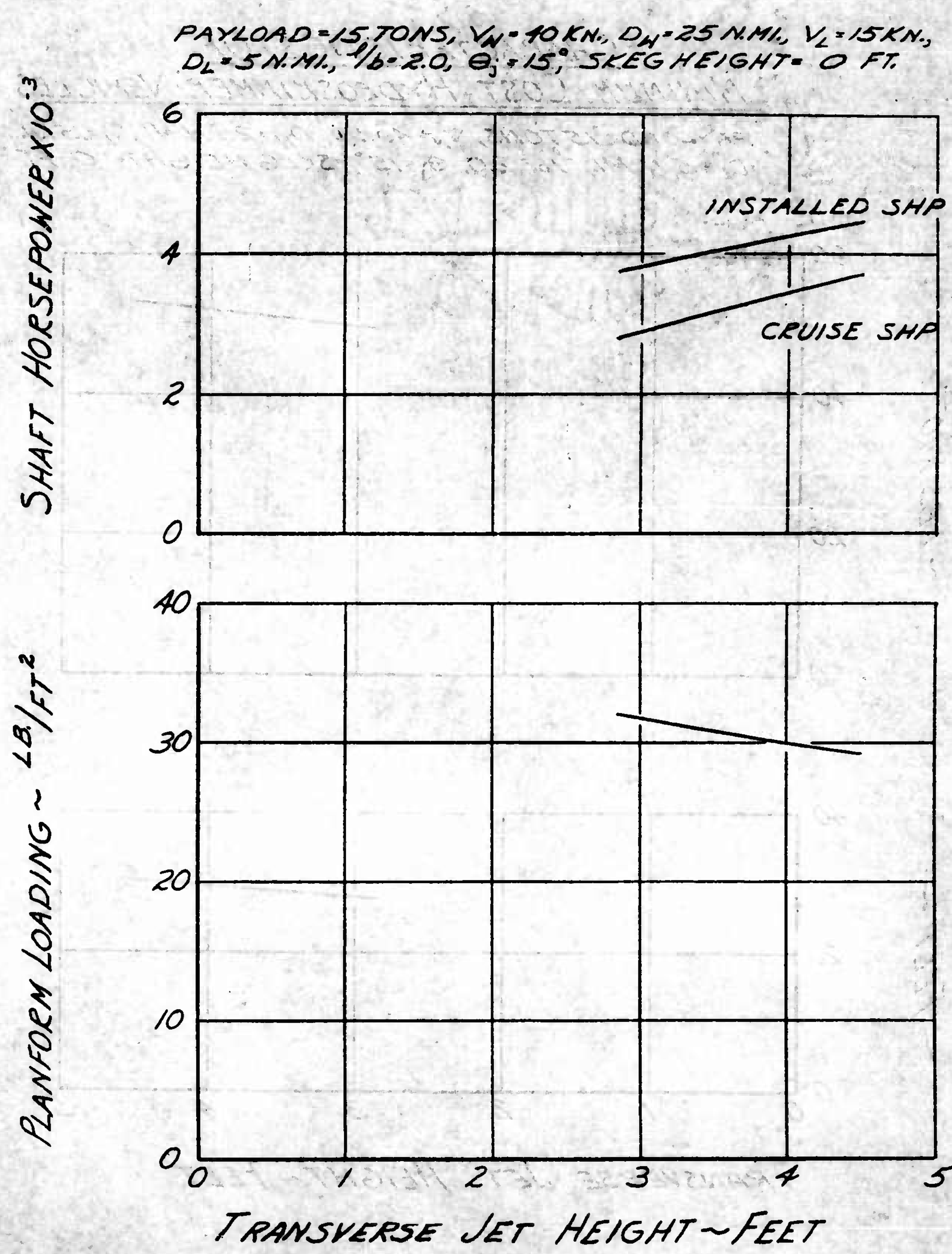


Figure V-70. Characteristics of Minimum Cost Hydroskimmer Vehicles.

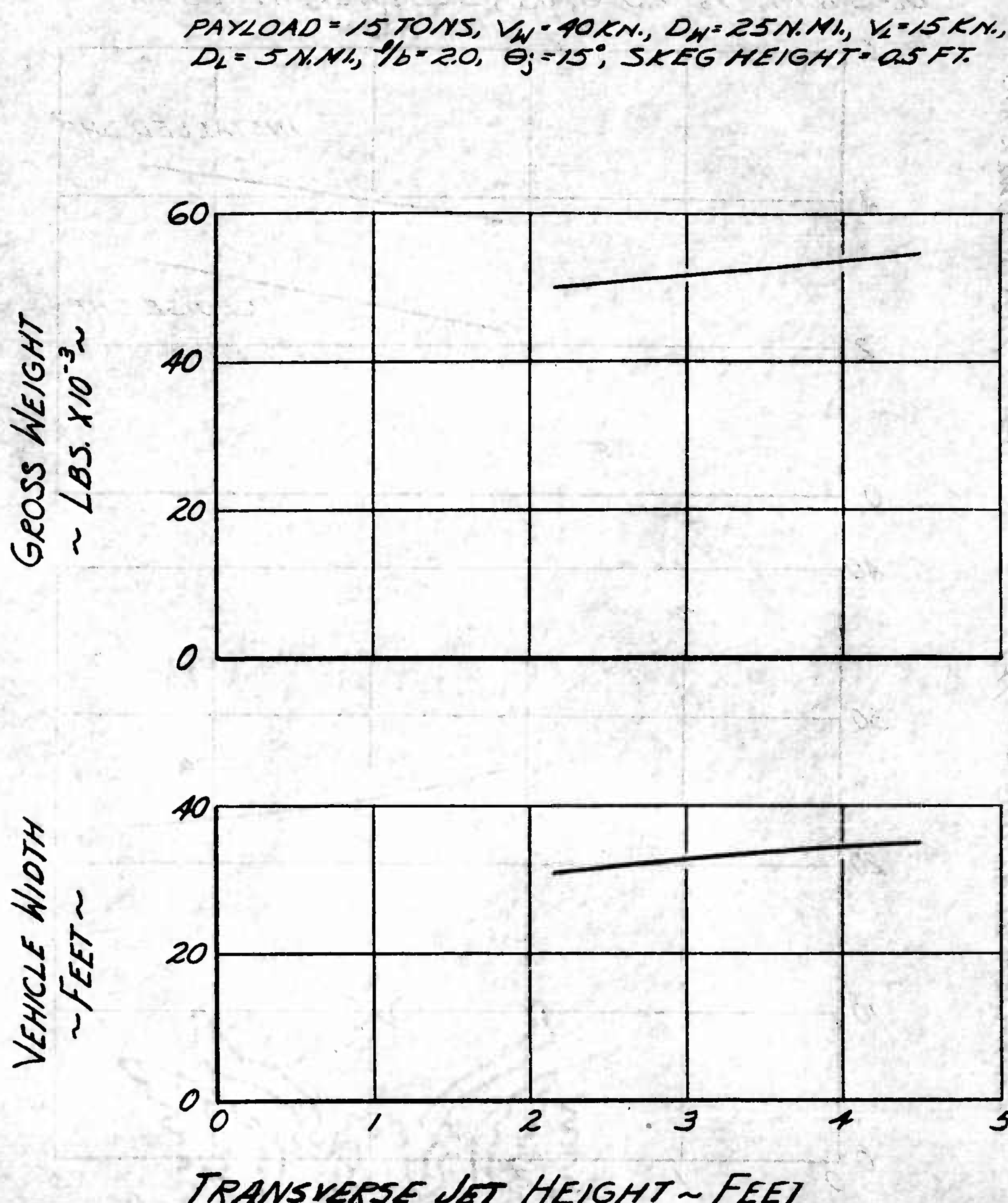


Figure V-71. Characteristics of Minimum Cost Hydroskimmer Vehicles.

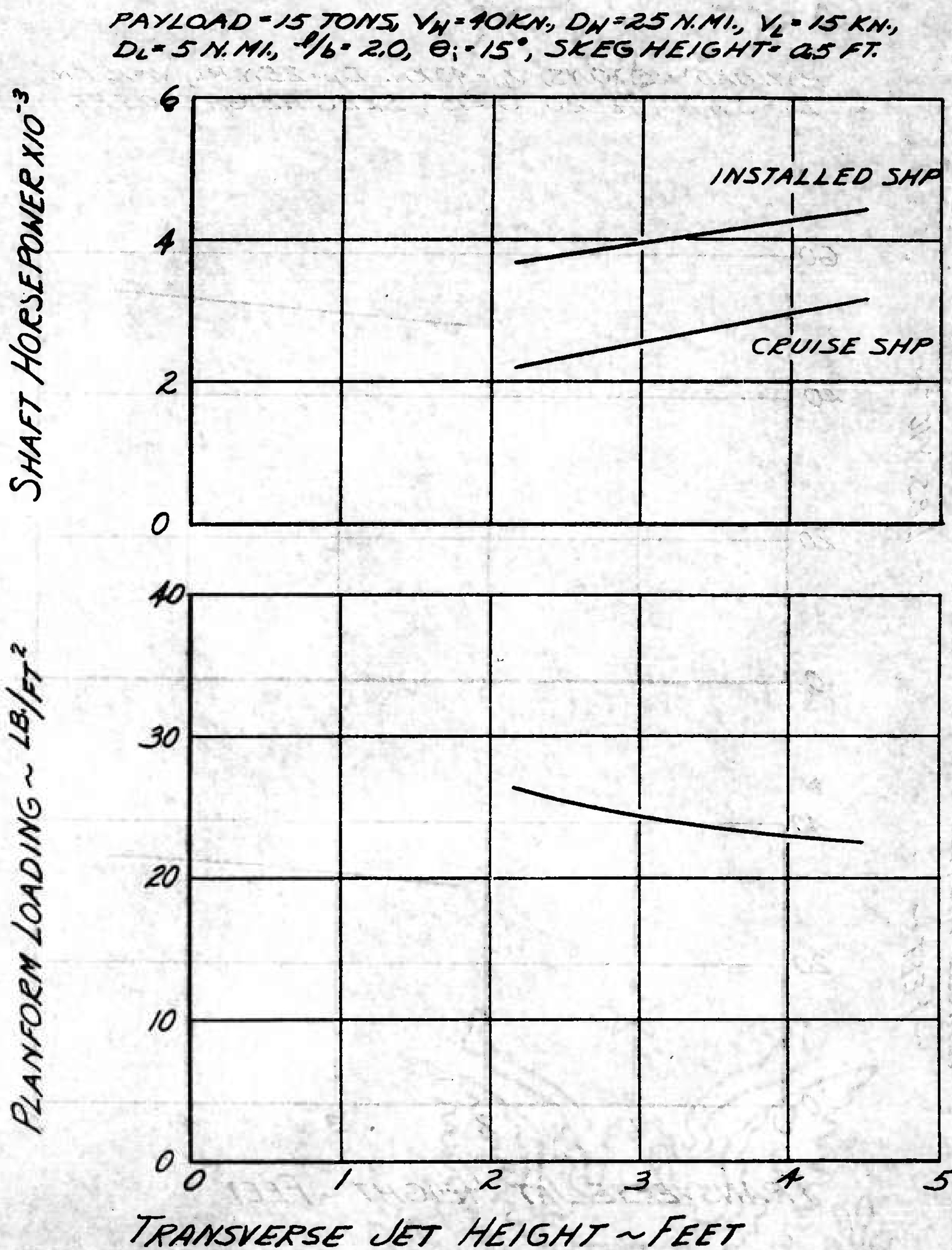


Figure V-72. Characteristics of Minimum Cost Hydroskimmer Vehicles.

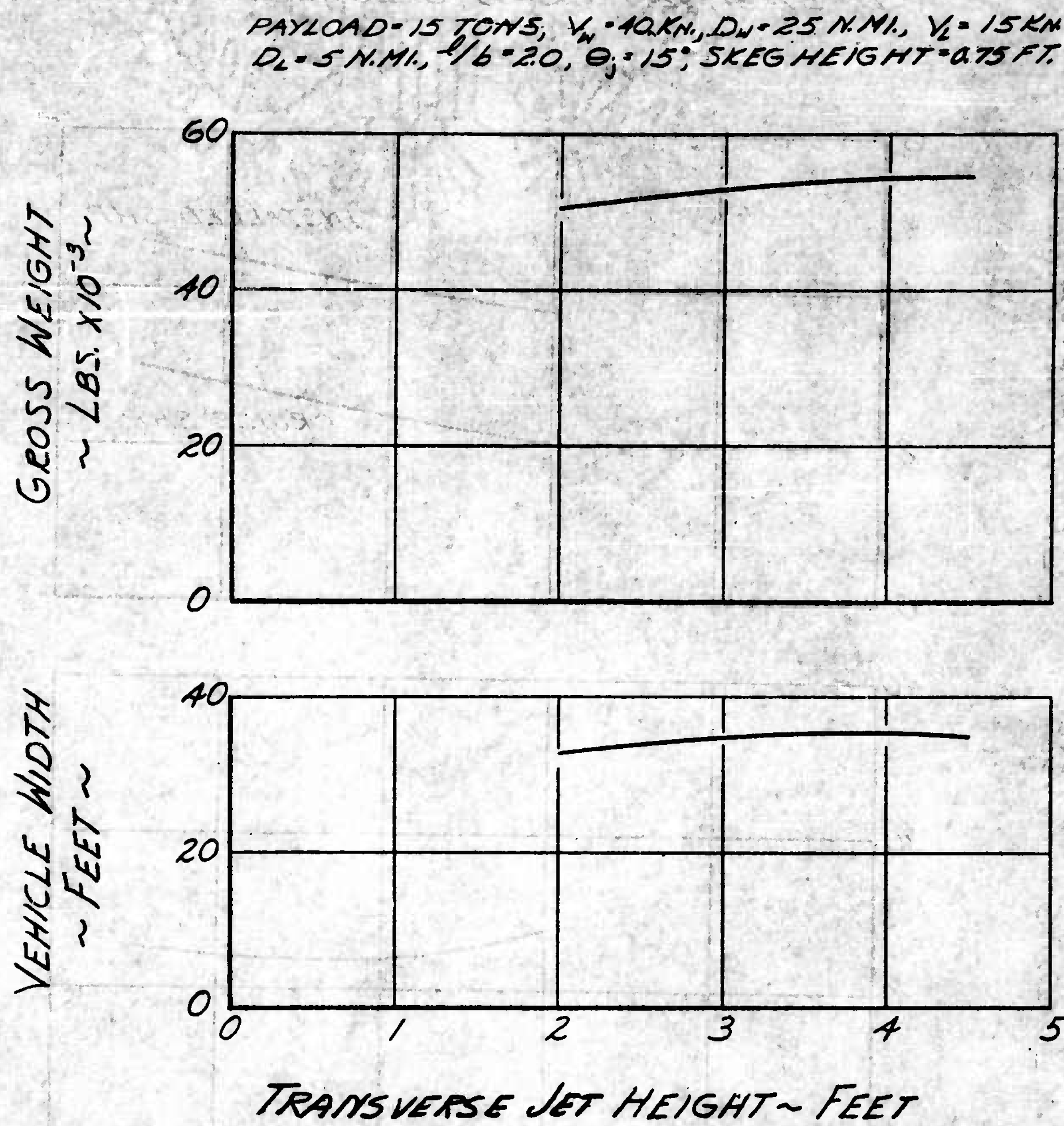


Figure V-73. Characteristics of Minimum Cost Hydroskimmer Vehicles.

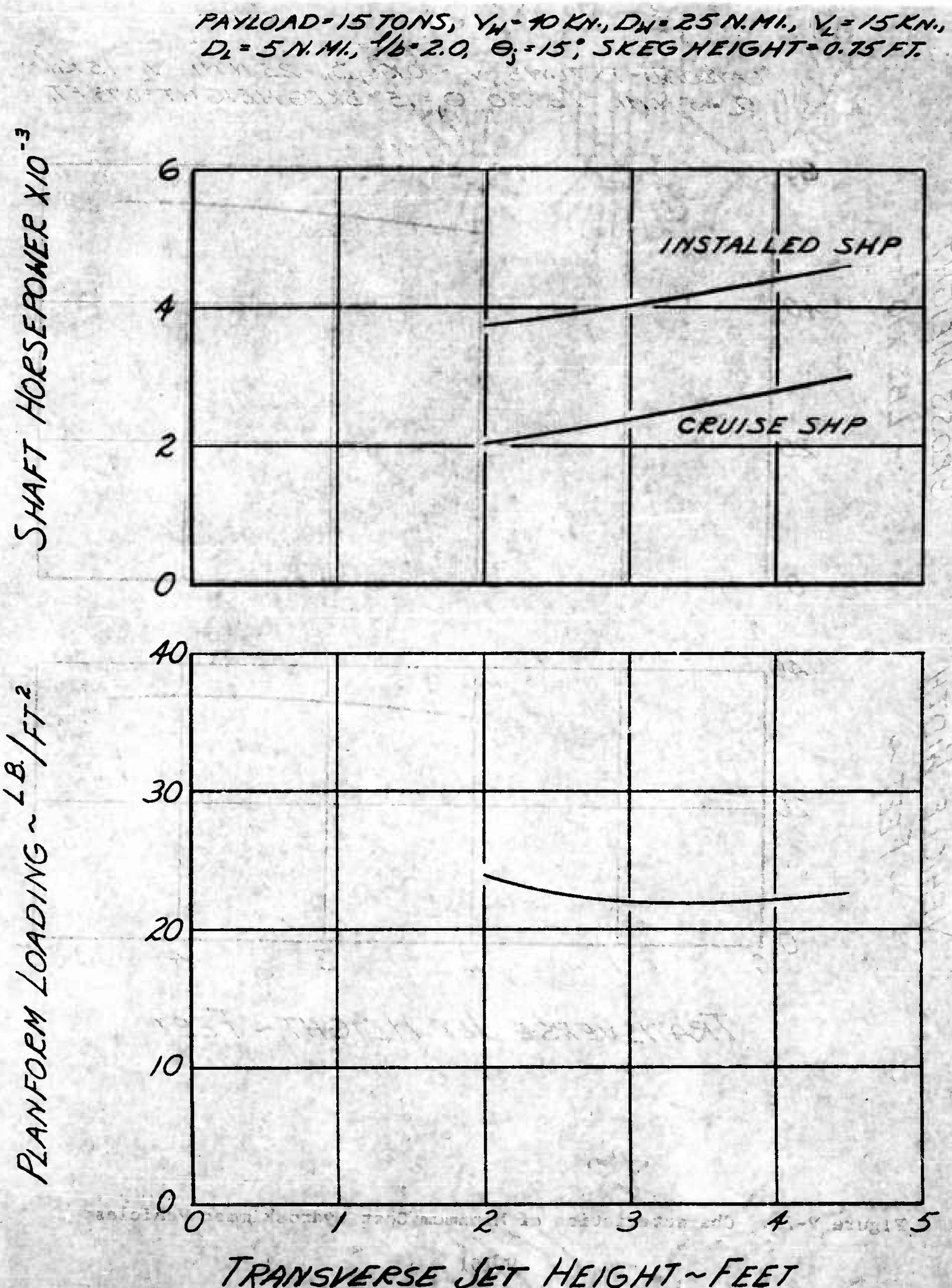


Figure V-74. Characteristics of Minimum Cost Hydroskimmer Vehicles.

G. COMPARISON OF AIR CUSHION VEHICLE TYPES

1. RECIPROCATING VERSUS TURBINE POWERPLANTS

A brief investigation to compare the costs and characteristics of turbine and aircraft type reciprocating engine powered air cushion vehicles was conducted. The vehicles were required to operate at 3.0 feet and perform missions composed of a 5 nautical mile inland radius at 15 knots and 5 to 75 nautical miles radius over water. In order to provide for a common base of comparison, the two reciprocating powered vehicles' speed of operation and payload were selected equal to those of the corresponding minimum lighterage cost turbine powered fully skirted and partially skirted air wall vehicles--40 knots, 15 ton payload and 80 knots, 10 ton payload, respectively.

The analyses of reciprocating powered vehicles employed propulsion system parameter values that differ from the nominal values used with turbine powerplants. The propulsion system parameter values used with the reciprocating powered vehicles are based on planning factor and engine specification data obtained from various engine manufacturers. The differing reciprocating engine propulsion system parameter values are presented in Table V-3 along with the nominal values used with the turbine powerplants.

TABLE V-3

POWERPLANT PARAMETER VALUES

PARAMETER VALUE	RECIPROCATING POWERPLANT	TURBINE POWERPLANT
Propulsion System Weight	2.5 LB/SHP	1.4 LB/SHP
Propulsion System Cost	$22/LB	$43/LB
Powerplant Cost	$27/SHP	$32/SHP
Specific Fuel Consumption	.5	.75
Fuel Cost*	.03/LB	.02/LB
Sum of Fan, Gearbox & Shafting Weight	1.3 LB/SHP	1.05 LB/SHP
Powerplant Weight	1.2 LB/SHP	.35 LB/SHP

*See Reference 5 for fuel costs

The sum of fan, gearbox and shafting component weights for the reciprocating powered vehicles were increased .25 pounds per shaft horsepower to allow for the impulse loads and vibration associated with reciprocating powerplants. The additional weight also provides allowance for clutch mechanisms between the fan and the reciprocating powerplants which are probably necessary to permit ease of starting the reciprocating powerplant and to eliminate the transmittal of starting surge loads to the shaft, gearbox and fan components.

The results of the reciprocating powerplant investigations are presented in comparison form on Figures V-75 through V-78.

Figures V-75 and V-76 compare the characteristics of turbine and reciprocating powered partially skirted air wall vehicles. At a 25 nautical mile over water radius the gross weight of the reciprocating powered vehicle is 14 percent greater than that of the turbine powered vehicle. However, vehicles powered by reciprocating powerplants have a lower increase in gross weight with increasing over water mission radius due to their better specific fuel consumption characteristics.

The daily lighterage costs of reciprocating powered vehicles are greater than that of the turbine powered vehicles. At the 25 nautical mile over water radius the lighterage cost increase is approximately 6 percent.

The installed and cruise shaft horsepowers of the reciprocating powered partial skirted vehicles, shown on Figure V-76, exceed those of turbine powered vehicles by approximately 10 percent, reflecting the gross weight increase. The fuel consumption of the reciprocating powered vehicles shown on Figure V-76, are reduced approximately 24 percent--a significant reduction in fuel expenditure.

Data on reciprocating and turbine powered fully skirted vehicles are presented on Figures V-77 and V-78. Figure V-77 presents the daily lighterage cost of vehicles powered by both powerplant types and indicates only a 2 percent cost increase for the reciprocating powered type. The gross weight of the reciprocating powered vehicles is shown to increase approximately 8 percent.

The fuel consumption, installed and cruise shaft horsepowers of

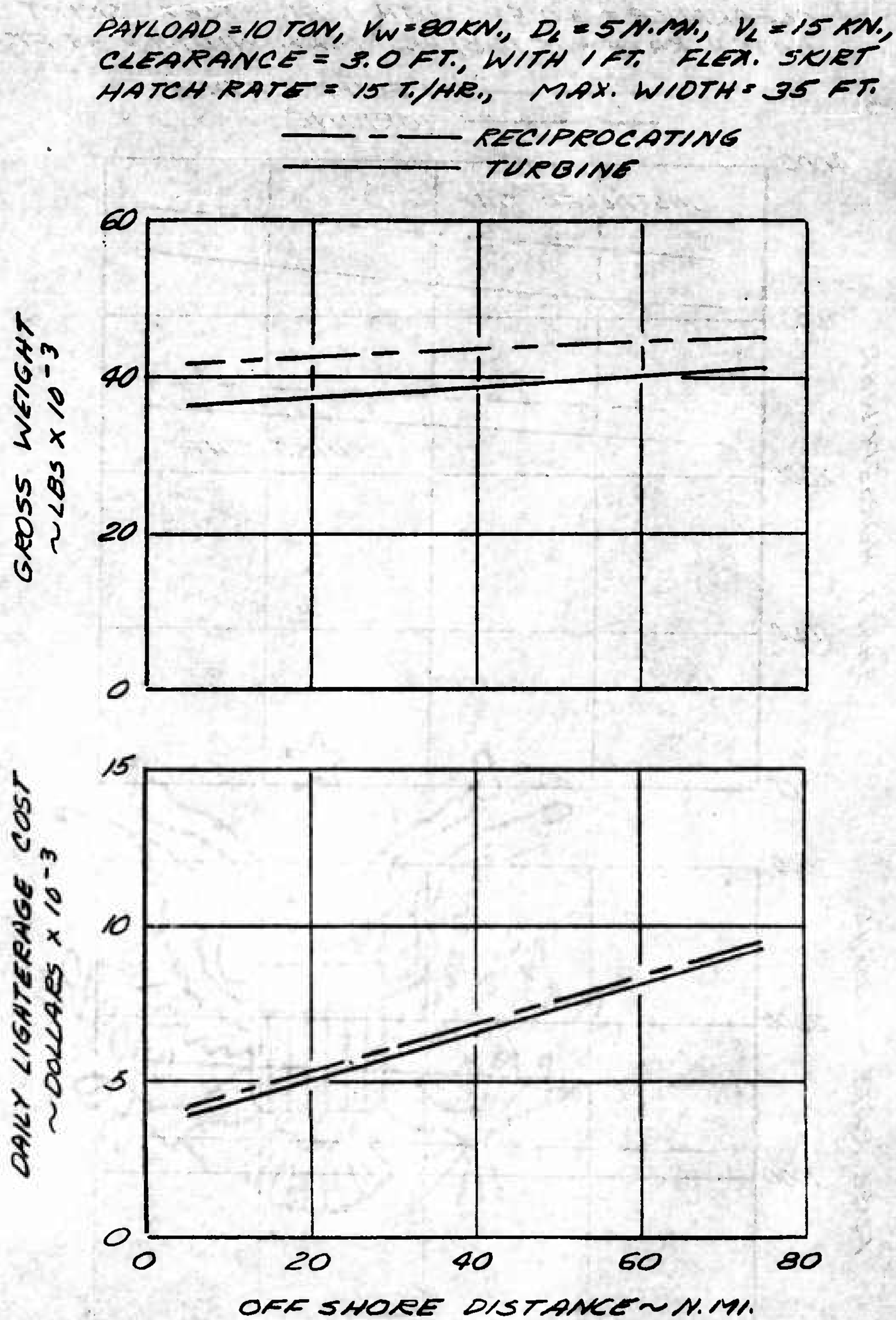


Figure V-75. Comparison of Turbine and Reciprocating Powered Partial Skirted Air Wall Vehicles.

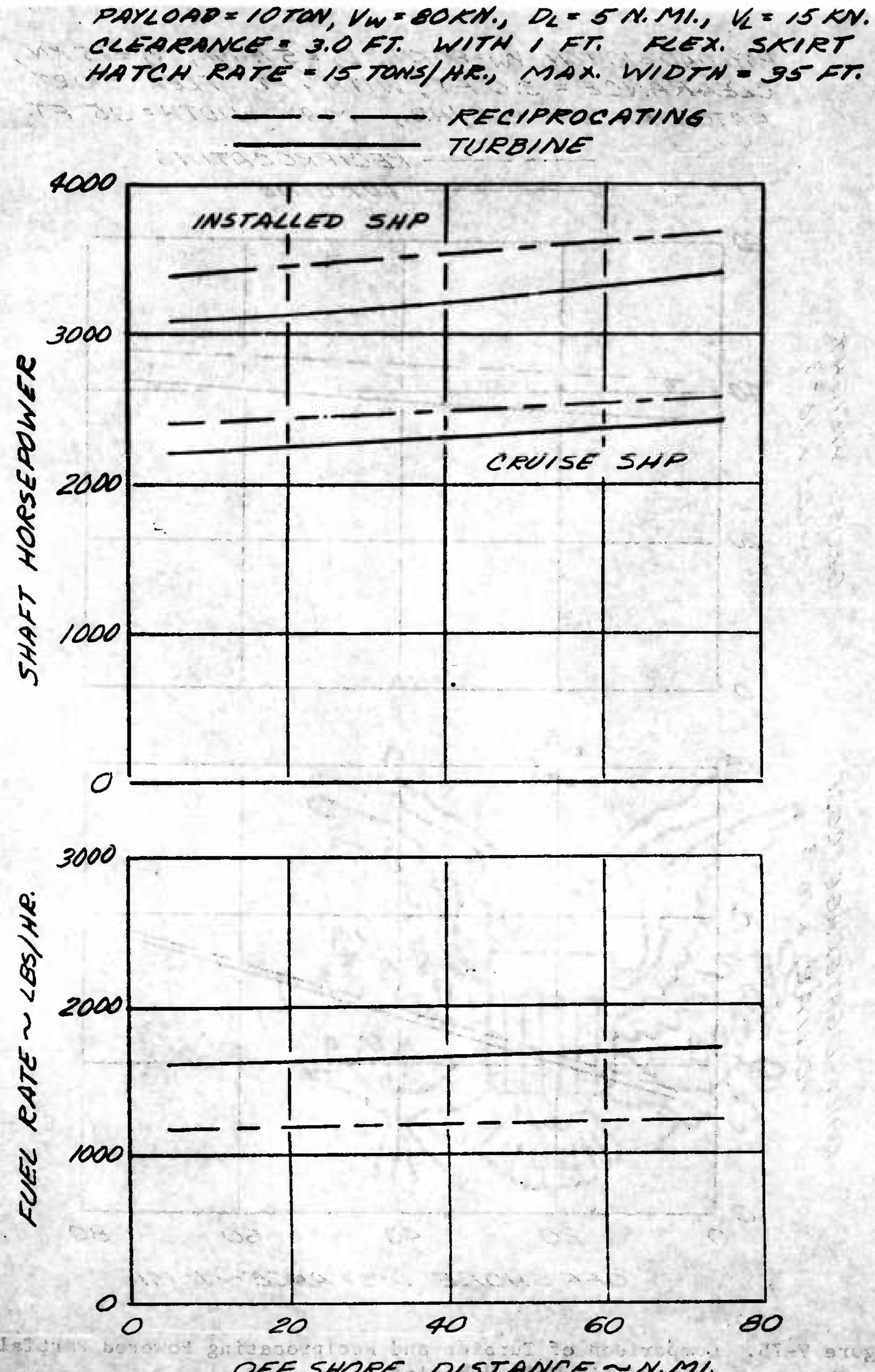


Figure V-76. Comparison of Turbine and Reciprocating Powered Partial Skirted Air Wall Vehicles.

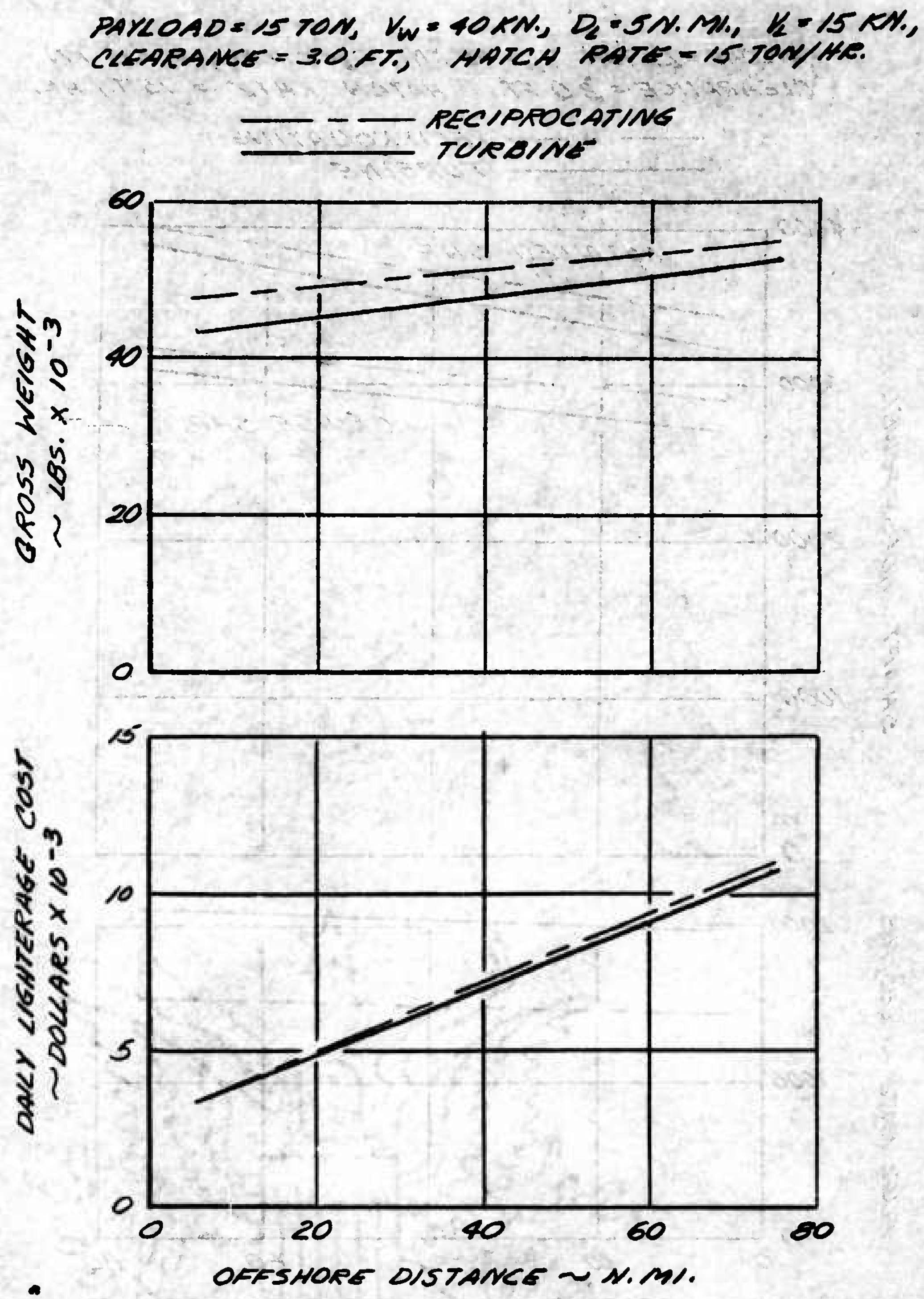


Figure V-77. Comparison of Turbine and Reciprocating Powered Skirted Air Cushion Vehicles.

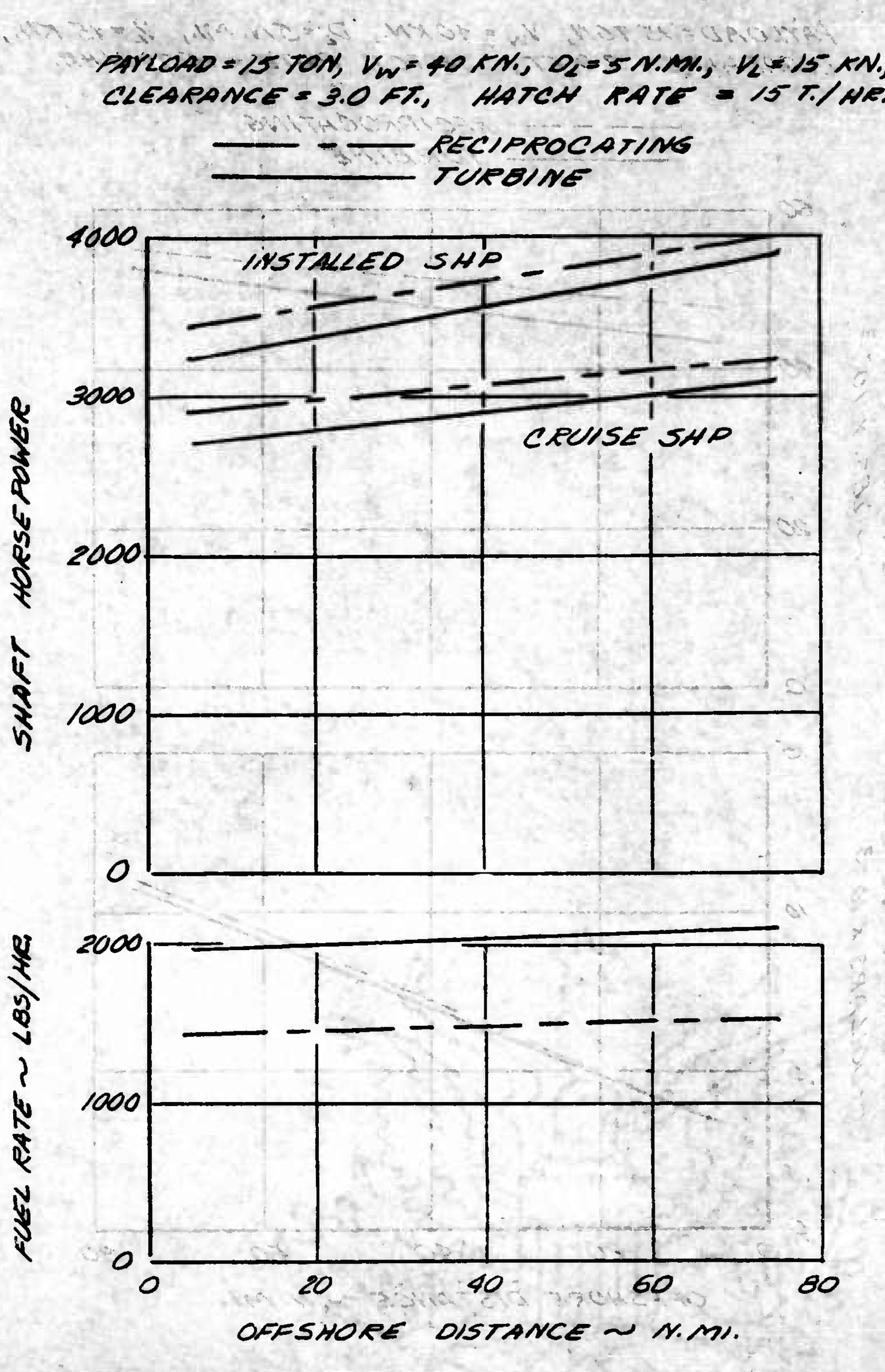


Figure V-78. Comparison of Turbine and Reciprocating Powered Skirted Air Cushion Vehicles.

reciprocating and turbine powered skirted vehicles, are shown on Figure V-78. The trend in percentage increase of the reciprocating powered skirted vehicle's installed and cruise power requirements are the same as the partial skirted vehicle's--diminishing as the overwater radius increases. The fuel consumption of the reciprocating powered fully skirted vehicles show approximately a 27 percent decrease from those powered by turbine engines.

The foregoing data comparing reciprocating and turbine powered air cushion vehicles indicate that LOTS mission vehicles powered by turbine powerplants have a weight, powerplant size and cost advantage with respect to vehicles using reciprocating powerplants. The fuel consumption of the reciprocating engine powered vehicles are, however, considerably reduced with respect to the turbine powered versions.

The reduced fuel consumption of the reciprocating powered units is attractive in view of the logistics problems associated with the transport of fuel to Army units in the field. However, other factors, such as the reduced maintenance requirements evidenced by equipments employing current turbine powerplants and the ability of turbine units to utilize fuels varying from kerosene through gasoline in addition to their permitting attainment of smaller sized vehicles with less operating expense lead to the selection of turbine powerplants in favor of reciprocating engines.

2. LIGHTERAGE COSTS

Minimum lighterage cost comparison of the various types of air cushion vehicles investigated is presented as a function of design over water radius on Figure V-79. The nominal cost and vehicle technology assumptions previously delineated are implicit in the presented data.

The data on Figure V-79 indicates that the simple air wall vehicle is less economical than the others at all over water radii considered. The partially skirted air wall vehicle is economically superior to the other air cushion vehicle types at water radii exceeding 25 nautical miles. The fully skirted

COMPARISON OF MINIMUM COST AIR CUSHION LIGHTERAGE VEHICLES

h = 3.0 FT., HATCH RATE = 15 TONS/HR., LAND DISTANCE = 5 N.MI., LAND SPEED = 15 KN., .25 'g' MANEUVER CAPABILITY, MAX. WIDTH = 35 FEET, DELAY TIME = .27 HR./CYCLE

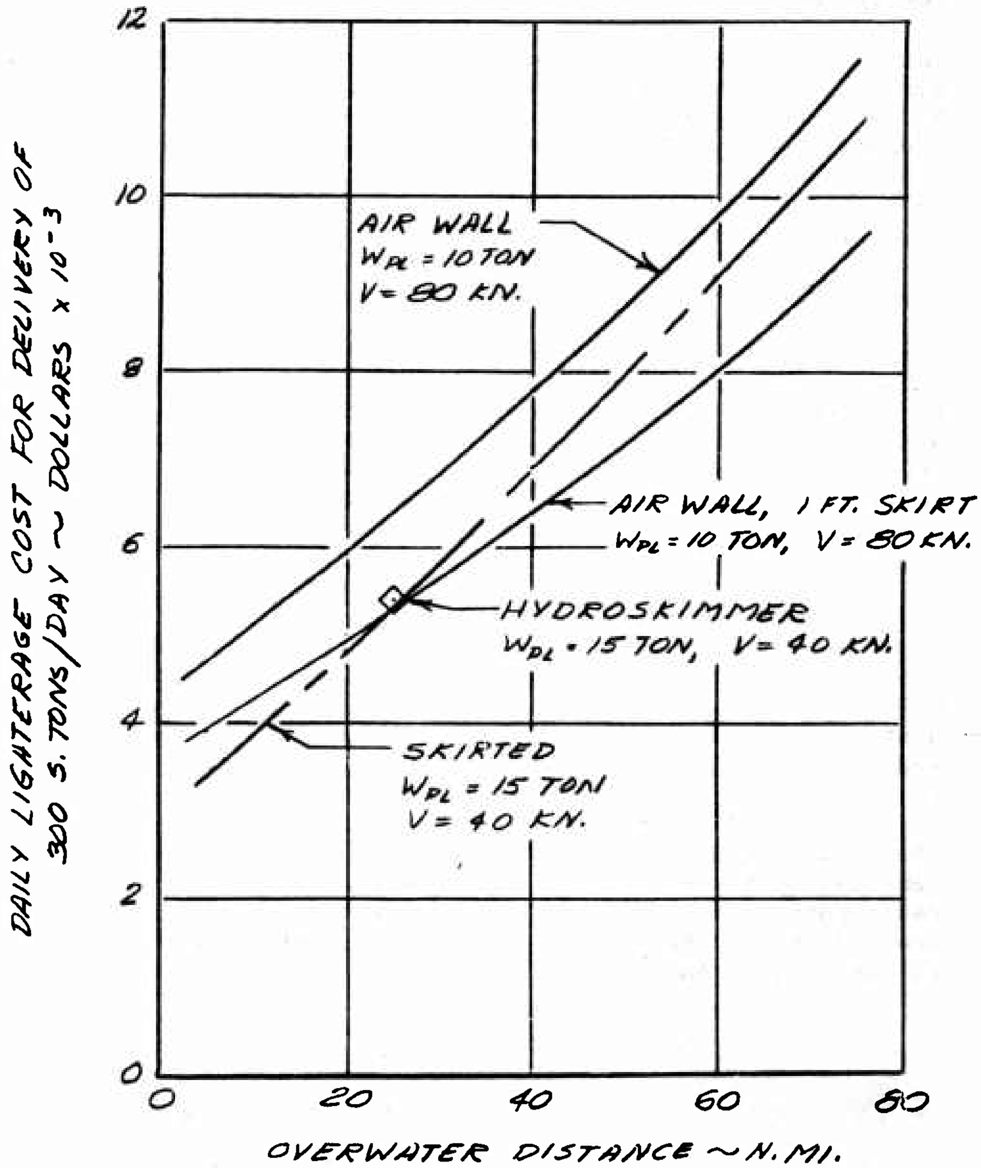


Figure V-79

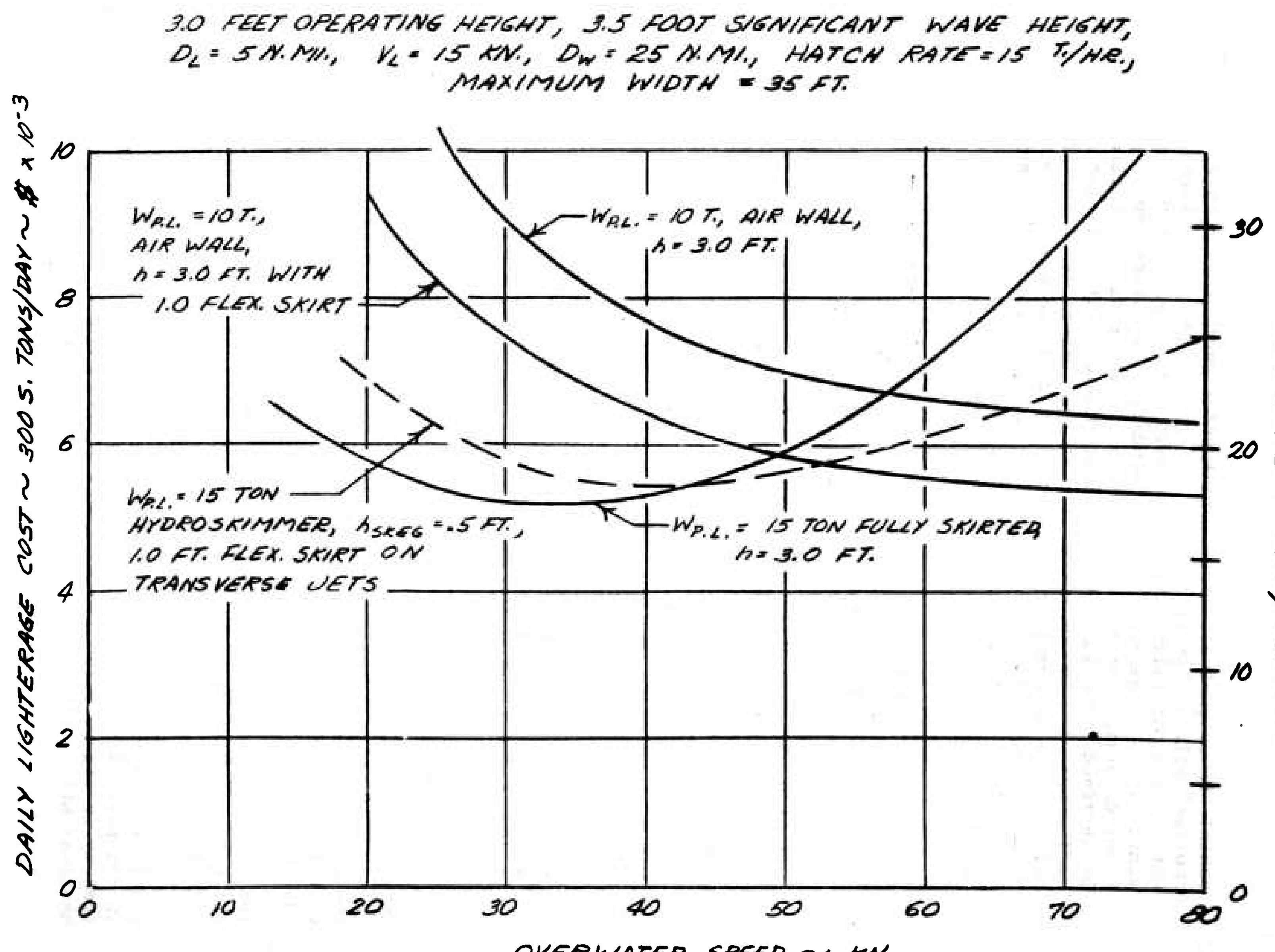


Figure V-80. Effect of Design Speed on Air Cushion Vehicle Lighterage Cost Minimum Cost Air Cushion Vehicle.

vehicle is economically superior at water radii less than 25 nautical miles. The differences in lighterage costs evidenced between the partially skirted air wall and fully skirted vehicles do not permit firm recommendation of either type. Exact determination of the overwater mission radius must first be obtained. Should the 25 nautical mile overwater mission radius selected by the contractor prove appropriate, then either vehicle type is considered economically satisfactory. Other factors dependent upon more detailed design investigation and currently unquantified operational flexibility requirements would then have to provide the necessary information for selection of one vehicle type in favor of the other.

Figure V-80 presents the lighterage cost of the various types of minimum cost air cushion vehicles as a function of their design speed. The mission radii of all vehicles are the same, 5 nautical miles inland and 25 nautical miles over water. A land speed of 15 knots is assumed identical for all vehicles. The payload of each type vehicle is held constant independent of the varying over water design speed and is selected on the basis of payload resulting in minimum lighterage cost at best over water design speed.

The data on Figure V-80 indicates the relative standing of the vehicles as design speed varies. At the low speeds (to 40 knots) the fully skirted vehicle is economically advantageous, while at the higher speeds (above 60 knots) the partially skirted vehicle is more economical. The hydroskimmer type vehicles show economy of operation which is between that attainable with either of the other vehicle types across the design speed range investigated.

The data again indicates that proper choice of vehicle type is dependent upon mission and operational flexibility requirements.

H. SELECTION OF AIR CUSHION VEHICLES FOR COMPARISON WITH WHEELED AMPHIBIANS

The results of the foregoing analysis of various types of air cushion vehicles do not provide clear delineation of economic advantage of one type vehicle over the others.

The hydroskimmer vehicle was eliminated from further comparison for the reasons previously stated--mechanical complication involved with skeg retraction for overland operation does not appear warranted since it does not have a clear cut economic advantage.

The 15 ton payload 40 knot fully skirted air cushion vehicle and the 10 ton payload 80 knot partially skirted air wall vehicle have equal economy in lighterage operations at a design mission radius of 5 nautical miles inland and 25 nautical miles over water. At their

design operating height of 3.0 feet they also have equal obstacle clearance capability. The operational and characteristic data of these two vehicles typify what is believed achievable with air cushion vehicles in LOTS operations. Their mission capabilities are compatible with current LOTS operation planning and probable future LOTS missions.

The fully skirted 15 ton payload and the partially skirted 10 ton payload air cushion vehicles were, therefore, selected for comparison with existing lighterage equipments. The primary characteristics of these vehicles, as determined by the analytic procedures used in this study, are presented in Table V-4 for ready information.

TABLE V-4

SELECTED AIR CUSHION VEHICLE CHARACTERISTICS

ITEM	FULLY SKIRTED 15 TON PAYLOAD	PARTIAL SKIRTED 10 TON PAYLOAD
Gross Weight	46,000 LB	37,500 LB
Planform Loading	55.5 LB/FT^2	19.6 LB/FT^2
Width	20.5 FT	31.5 FT
Length	41 FT	63.0 FT
Base Area	831 FT^2	1907 FT^2
Installed Power	3,400 SHP	3,160 SHP
Weight Empty	11,200 LB	15,300 LB
Max. Cruise Power	2,800 SHP	2,270 SHP
Cruise Fuel Consumption	2,015 LB/HR	1,645 LB/HR
Operating Height	3.0 FT	3.0 FT
Design Maneuver	.25 'g'	.25 'g'
Design Grade	25%	25%
Max. Grade	32%	40%
Initial Cost (Prod.)	$247,000	$253,400
Daily Lighterage Cost (Design Mission)	$ 5,300/day	$ 5,350/day
Hourly Cost	$94/HR	$88/HR

Design sketches of the two analytically determined vehicles were prepared in order to indicate their ability to accommodate desired cargo handling provisions and permit packaging of the necessary propulsion system components. No attempt was made to quantify vehicle weights or perform structural design analyses as these are considered beyond the program scope. Additionally, detail design study to provide the most efficient cargo handling arrangements and cargo compartment space was not permitted by contract time and funds.

Design Sketch A depicts the 10 ton payload partially skirted vehicle. Notable features of this vehicle are:

(1) The fold-away bow for ease of transhipment on MSTS vessels and for permitting lowering of the 15° slope vehicle roll-on, roll-off bow ramp.

(2) Cargo compartment having minimum clear dimensions of 13 feet width, 60 feet length and 11 feet height--dimensionally adequate to handle all military vehicle equipments to be lightered. It is anticipated that no space limitation problems will be encountered in filling this vehicle's cargo compartment to its maximum capacity (25 tons) when environments permitting a 1.8 foot operating height are present.

(3) Overhead traveling hoist for cargo positioning and, when aft door rail extensions are opened, self cargo discharge to the ground or to trucks.

(4) Stevedoring and other personnel safety considerations in the form of combined turning vane and safety grills on the lifting fans; combined stator blade and safety grills on the shrouded propulsion fans and vehicle side railings. Additionally, opened hatch doors provide stevedoring personnel walkways and flush cargo compartment ladders permit egress and entry to the cargo compartment.

(5) Four pairs of large tired wheels provide direct ground support and permit power-off towed vehicle movement during maintenance.

(6) Shrouded propulsion and lateral acceleration fans provide for 14° relative ship to lighter roll and 15° roll with

respect to a boom lowered cargo draft. These roll angle allowances are considered adequate for compensating ship-lighter relative motion during shipside loading operations. Additionally, clear area between the fans combined with the integral traveling hoist permit most cargoes to be loaded between the longitudinally displaced propulsion-acceleration fans with little danger of fan damage.

(7) Large inflatable bumpers permit lighter-to-ship contact during shipside cargo handling with minimum structure loads to either vehicle or ship.

(8) Simple spray deflectors, similar to those tested by NASA and developed by others are incorporated on the vehicle's bow to minimize water spray.

Design Sketch B depicts the fully skirted vehicle. The smaller size of this vehicle in spite of its 50 percent greater payload is apparent.

The cargo handling, environmental and personnel safety provisions shown for the fully skirted vehicle are similar to those enumerated for the partially skirted vehicle.

To illustrate another concept the integral mounted traveling hoist cargo handling gear of the partially skirted air wall vehicle is replaced in the fully skirted vehicle with a powered continuous conveyor belt spanning the width of the cargo compartment. Rapid cargo positioning and self unloading are, therefore, maintained with the fully skirted vehicle.

To provide adequate cargo clear space within the smaller size of this vehicle it is desirable to split the propulsive and maneuvering thrust capabilities such that approximately one-half the maneuver propulsive force is integrated with the lift system and the other half is obtained from the external aft-mounted shrouded and swiveling fans. The fans swivel 90° during shipside loading to provide for clearance with the ship and cargo compartment.

The cargo compartment of the fully skirted vehicle has dimensions of 11 feet width and 35 feet length--adequate to handle all vehicular equipments within its payload capacity. To illustrate another concept no cargo compartment cover is provided the fully skirted vehicle. The 40 knot cruise speed is considered low enough to not impose more than negligible aerodynamic drag penalties. The low lifting air flow volume of the skirted vehicle combined with spray deflectors and its

relatively low 40 knot cruise speed should minimize the driven spray and dust problems associated with an open cargo compartment configuration.

The considerations of propulsive system efficiency and vehicle signature-from-noise lead to selection of multiple small diameter fans for both vehicles. Such fans provide simplicity in ducting and coupled with continuously contracting duct area permit good distribution of lifting air flow volume. The relatively low tip speeds (500 to 600 feet per second) of the small diameter fans serve to minimize fan noise. Additionally, location of the turbine engines within the lifting air flow ducting permits suppression of sound from turbine compressor and turbine.

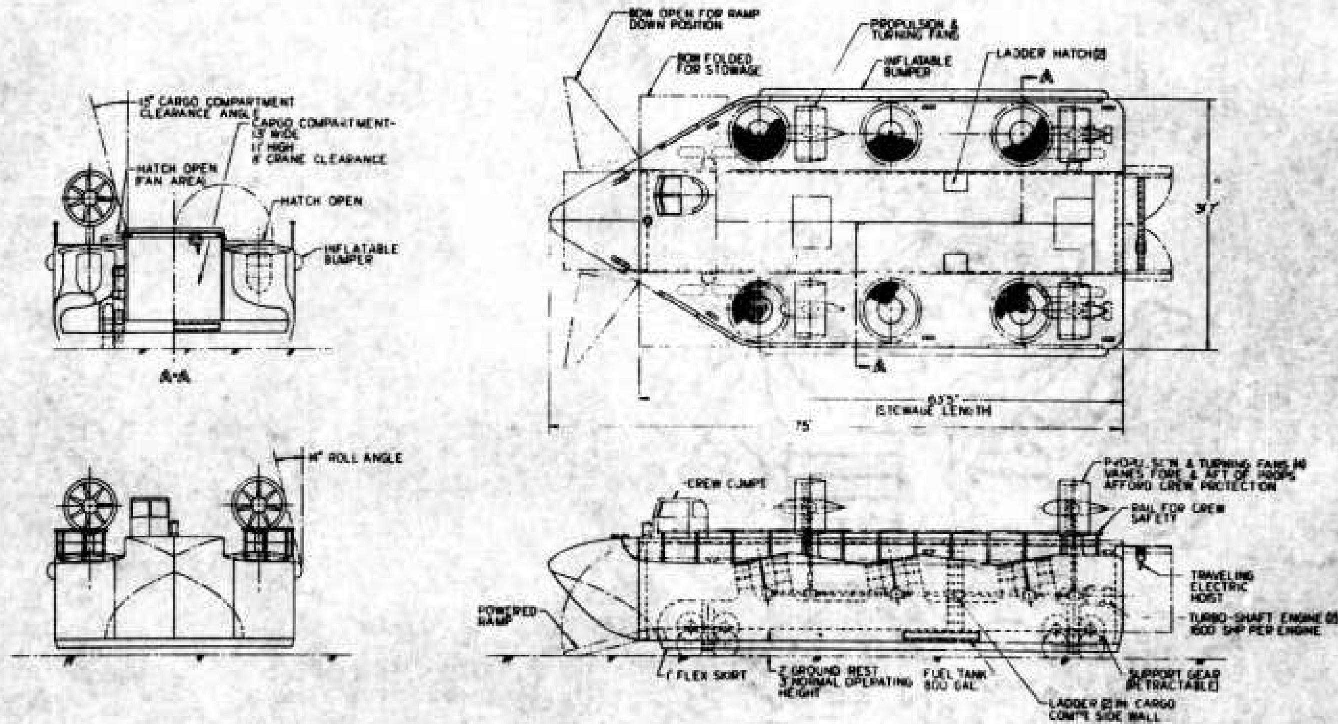
The turbine engine exhaust of both vehicles are exited into the lifting air flow to permit rapid dissipation of exhaust gasses and thus minimize the signature to infrared seeking devices.

Attention is again brought to the fact that the presented design sketches merely serve to indicate that the analytically determined vehicles can in fact accommodate the components and features vital to their operational use. As indicated by the previously presented data on vehicle planform loading variations, small (5 to 10 percent) changes to vehicle size can be accomplished to obtain more efficient operational characteristics with only minor alterations to vehicle costs. Additionally, it is anticipated that a refined design analysis, based on more precise structural and flexible skirt characteristic data, would indicate that the minimum lighterage cost air cushion vehicle for LOTS operations is an amalgamation of the vehicles presented.

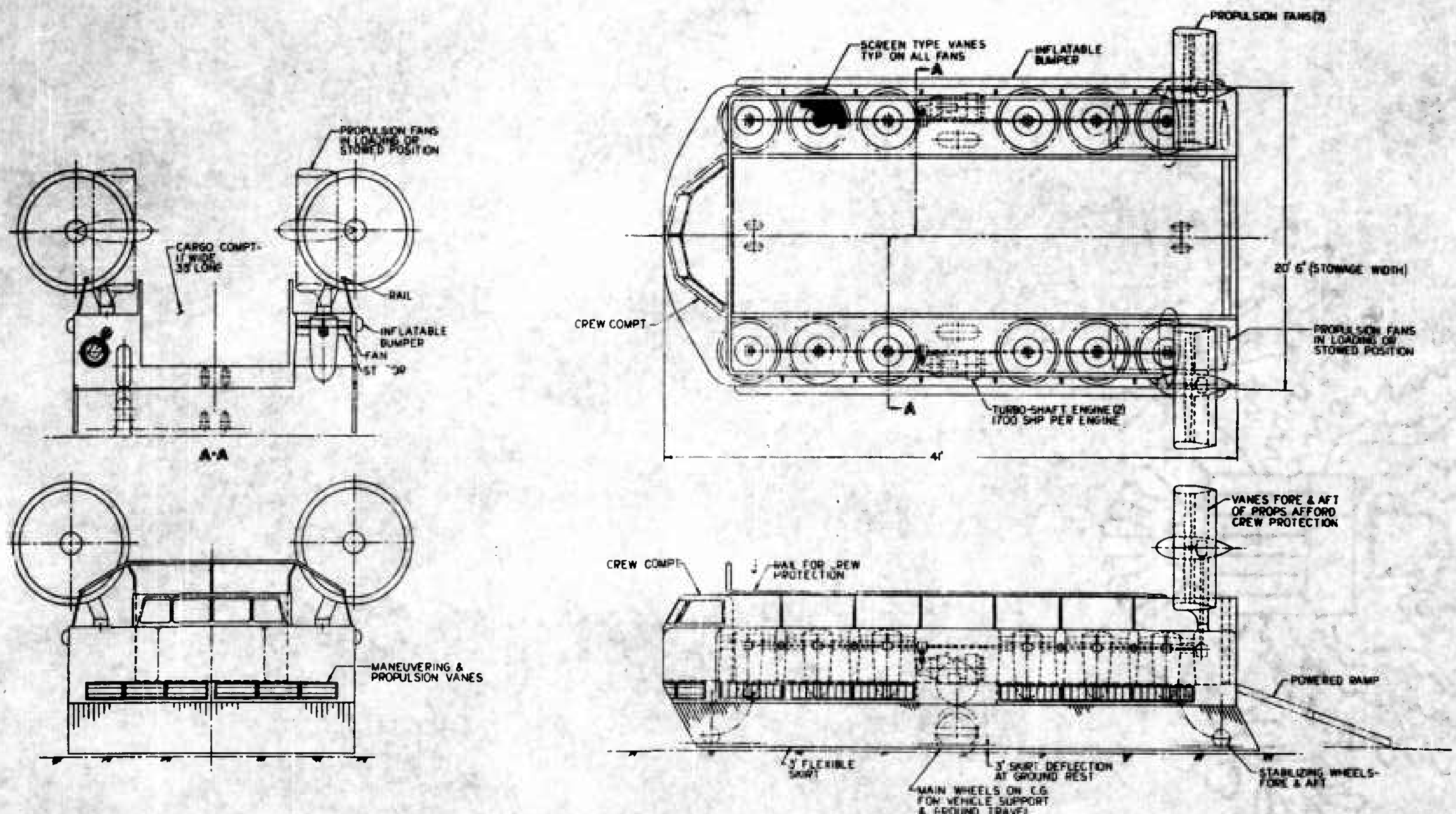
1. ACCELERATION CAPABILITIES

a. Partially Skirted Vehicle

The approximate acceleration capabilities of the partially skirted 10 ton payload air cushion vehicle designed for 80 knot overwater operation and mission radii composed of 5 nautical miles inland at 15 knots and 25 nautical miles over water are presented on Figure V-81. The presented data considers the vehicle to be operating on a smooth surface at design gross weight of 37,500 pounds and design operating height of 3.0 feet. An omni-directional maneuver



DESIGN SKETCH "A"
PARTIALLY SKIRTED AIR-WALL VEHICLE
10 TON PAYLOAD
V_c = 80 KNOTS



DESIGN SKETCH 'B'
FULLY SKIRTED VEHICLE
15 TON PAYLOAD
V_c = 40 KNOTS

capability of .25 'g' is available at the design hovering condition. Lateral acceleration capability of .25 'g' is assumed to be obtained at all speeds by means of propulsive effort. Additional lateral acceleration capability is possible by means of aerodynamic surfaces and/or forces created by side slip. The forward acceleration capabilities of the vehicle are estimated on the basis of fixed size external fans but are equally obtainable through use of louvered jet exits in the vehicle sides or a combination of external fans and louvered jet exits. The deceleration capabilities of the vehicle are based on conservative estimates of external fan performance in reverse pitch.

b. Fully Skirted Vehicle

The acceleration capabilities of the 15 ton payload fully skirted vehicle designed for 40 knot overwater operation are based on similar assumptions as employed in deriving the data for the partially skirted vehicle. The fully skirted vehicle acceleration characteristics over a smooth surface at design operating height of 3.0 feet and design gross weight of 46,000 pounds are shown on Figure V-82.

Deceleration characteristics and capabilities of the fully skirted vehicle are similar to those of the partially skirted vehicle.

2. SLOPE CLIMBING CAPABILITIES

The slope climbing capabilities of the partially skirted and fully skirted vehicles are shown as a function of forward speed on Figure V-83.

Both vehicles have approximately the same slope capability at their design gross weight and operating height (slightly in excess of 25 percent at almost zero speed). The small differences evidenced are the result of slightly different propulsion efficiencies. The skirted vehicle suffers a slight penalty in propulsive efficiency due to the fact that its basic size does not permit use of a larger propulsive flow area.

PARTIAL SKIRTED AIR WALL VEHICLE
ACCELERATION CAPABILITY
AT GROSS WEIGHT

SIDE AND STATIC THRUST = 5 LB/SHP, η_p = 82%
AT CRUISE, h = 3.0 FT., PAYLOAD = 10 TONS
GROSS WEIGHT = 37,500 LB., 1 FT. FLEX. SKIRT,
INSTALLED SHP = 3170

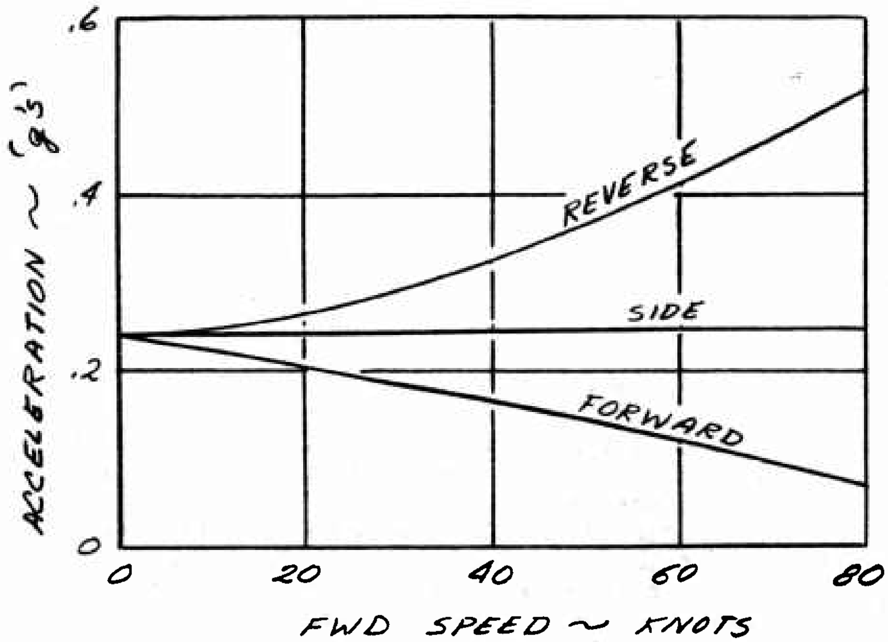


Figure V-81

FULLY SKIRTED VEHICLE
ACCELERATION CAPABILITY
AT GROSS WEIGHT

SIDE AND STATIC THRUST = 5 LB/HP, η_P = 0.75 AT 40 KN. CRUISE, h = 3.0 FT., PAYLOAD = 15 TONS, INSTALLED SHP = 3420, GROSS WEIGHT = 46,000 LB.

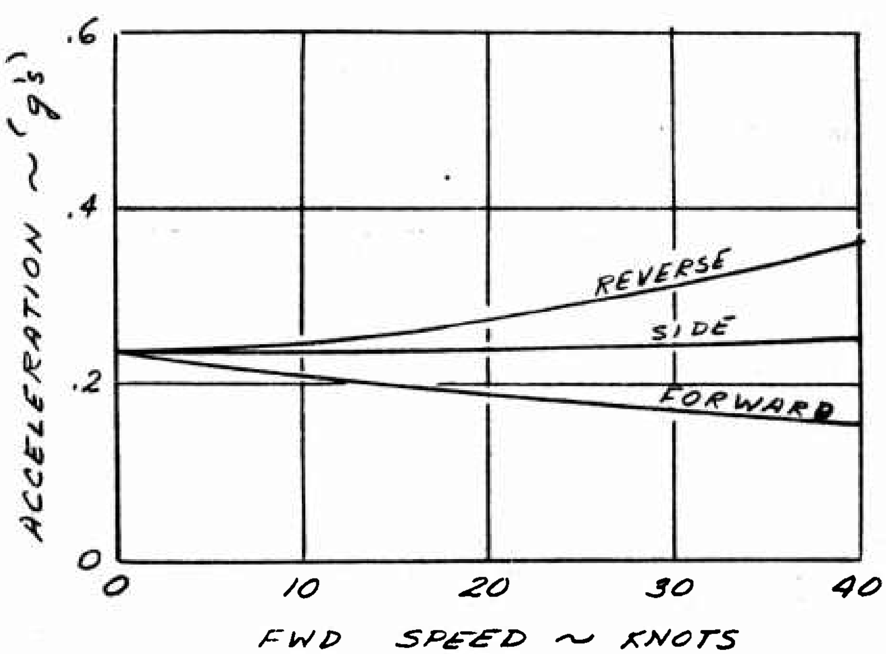


Figure V-82

The grade capability of the two vehicles at reduced operating height is also presented on Figure V-83. The increase in grade capability results from transfer of lift power to the propulsive elements of the propulsion system. The fully skirted vehicle requires substantially less lift power per unit weight than the partially skirted vehicle and consequently has proportionately less power to transfer to the propulsive units when a reduction in operating height is accomplished.

The skirted vehicle achieves a slope capability of 30 percent at gross weight and a speed of approximately 5 knots.

The partially skirted vehicle achieves almost 40 percent slope capability at design gross weight when the bottom edge of the skirt just touches the ground. With the skirt bottom edge six inches above the ground (h = 1.5 feet) the partially skirted vehicle has a 30 percent slope capability at approximately 20 knots and a maximum slope holding capability of approximately 35 percent.

It is noteworthy that the partially skirted ACV achieves the 40 percent gradeability of wheeled amphibious lighters (LARC-BARC). (Reference 17)

I. SPECIAL VEHICLES FOR TRANSHIPMENT

Investigations of transhipment of the selected air cushion vehicles (see Section III E of this report) indicated that some improvement in ease of transhipment could be obtained by reductions to the size of the vehicles. Two additional vehicles, especially sized for easier transhipment, were therefore analytically determined. One vehicle, employing one foot long skirts and the air wall concept, was limited to 24 foot width by 60 foot length and was designed to carry a 10 ton payload at an operating height of 3.0 feet and overwater speed of 80 knots. The other vehicle is fully skirted and limited to 19 foot width by 35 foot length and was designed to carry a 15 ton payload at an operating height of 3.0 feet and overwater speed of 40 knots. The previously selected mission capabilities of 5 nautical miles over land at 15 knots and 25 nautical miles over water were imposed on these vehicles.

The significant cost and physical characteristics of the especially-sized vehicles are compared with their corresponding minimum lighterage

SLOPE - CLIMBING CAPABILITY OF AIR CUSHION VEHICLES AT GROSS WEIGHT

HEIGHT INDICATED IS TO HARD STRUCTURES

——— PARTIAL SKIRTED AIRWALL VEHICLE

– – – – FULLY SKIRTED VEHICLE

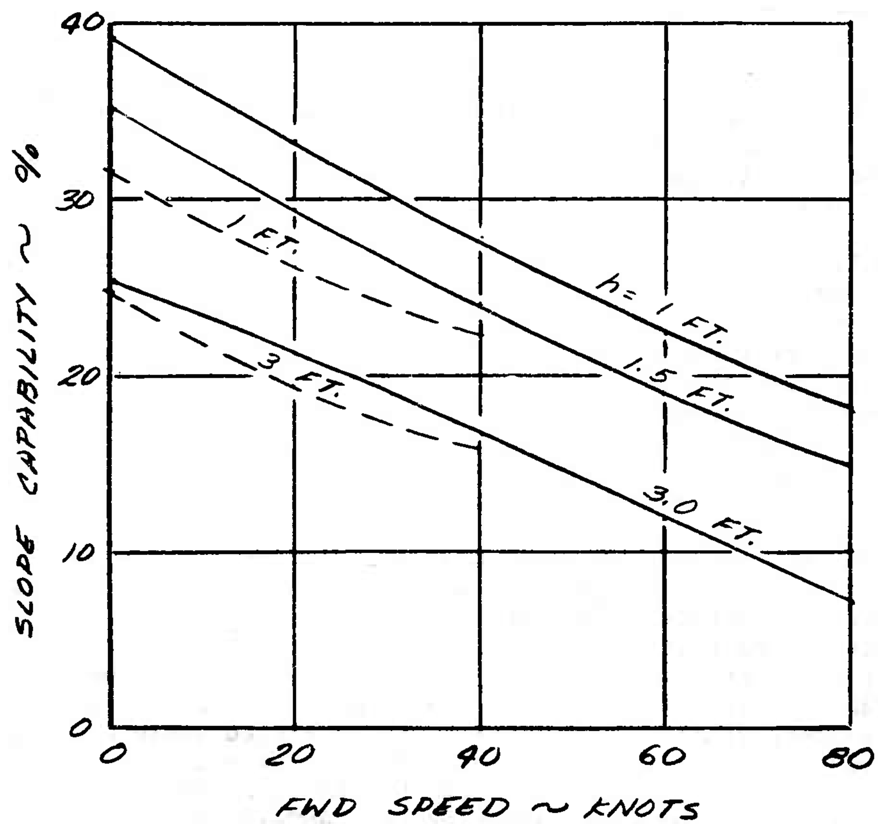


Figure V-83

cost vehicles in Table V-5

TABLE V-5

COMPARISON DATA SPECIALLY SIZED VEHICLES

ITEM	SPECIAL 15 TON FULLY SKIRTED	SELECTED 15 TON FULLY SKIRTED	SPECIAL 10 TON PARTIAL SKIRTED	SELECTED 10 TON PARTIAL SKIRTED
Gross Weight	45,500 LB	46,000 LB	36,900 LB	37,500 LB
Initial Cost	$255,600	$247,000	$278,900	$253,500
Lighterage Cost	$5,375/day	$5,300/day	$6,060/day	$5,350/day
Fuel Consumption	1,974 LB/HR	2,015 LB/HR	2,044 LB/HR	1,645 LB/HR
Hourly Cost	$95/HR	$94/HR	$101/HR	$88/HR
Installed Power	3,650 SHP	3,400 SHP	3,800 SHP	3,160 SHP
Size, Width/Length-Ft.	19 x 35	20.5 x 41	24 x 60	31.5 x 63

The gross weight of the especially sized vehicles are slightly lower when compared to their corresponding minimum lighterage cost vehicles. The installed power and costs of the especially sized vehicles are higher when compared to their corresponding vehicles.

The limited size partially skirted vehicle, when compared to the minimum cost partially skirted vehicle, shows an operating cost increase of 15 percent which is mainly attributable to the 24 percent increase in fuel consumption. The reduced size fully skirted vehicle shows an operating cost increase of only one percent when compared to its minimum cost counterpart. While the size limitation does not cause an appreciable cost increase to the fully skirted type vehicle, it does impose very significant constraints on the vehicle's cargo compartment size.

It was previously indicated that the minimum cost fully skirted vehicle is able to accommodate the vehicular equipments and other dry cargoes within its rated payload capacity. The limited size skirted vehicle's additional restriction of 1.5 foot width and 6 foot length would probably be manifest in its cargo compartment size. It is assumed, therefore, that the cargo compartment of the limited size skirted vehicle would measure 9.5 feet wide by 29 feet long. The net result is a vehicle which is limited in its ability to carry cargo in approximately the same manner as the LARC-15, which according to

Reference 38 normally carries approximately two-thirds of its rated payload. Should this prove true, then the real operating costs of the 15 ton payload limited size skirted vehicle would rise approximately 50 percent above its unlimited size counterpart. (It should be noted that the limited size partially skirted 10 ton payload vehicle is not estimated to encounter the cargo compartment size limitations of the reduced size fully skirted vehicle.)

J. CONCLUSIONS AND RECOMMENDATIONS

Many intermediate conclusions have been drawn during the foregoing discussions of air cushion vehicle analyses. Enumeration of all conclusions previously stated will serve no useful purpose. There are, however, several significant conclusions discerned from the data presented which bear emphasis. These are:

1. The use of skirting on air cushion vehicles provides for minimum cost and efficient vehicle physical characteristics. Based on the nominal estimates and assumptions, two skirted configurations showing superior lighterage economies than the simple air wall air cushion vehicles are recommended by the study. The configurations have significantly dissimilar technical characteristics which result from the degree of flexible skirting employed. The sensitivity of vehicle configuration to degree of flexible skirting emphasizes the need for additional test and analytic studies to properly refine air cushion vehicle design.

2. Sensitivity analyses of the air cushion vehicle show that changes to individual assumed costing parameters by as much as 50 percent result in only nominal changes to vehicle physical characteristics. These variations do not materially affect the relative economic standing of the vehicle types. The analytic procedures used herein to determine characteristics of minimum cost ACVs can therefore be utilized with a high degree of confidence that differences between an initially assumed cost parameter and its actual value will not change the vehicle configuration significantly. However, if several cost parameters are simultaneously assumed either too conservatively or too optimistically, then significant changes to both cost and vehicle configuration can occur.

3. The sensitivity analyses of air cushion vehicles also show that vehicle costs are especially sensitive to assumptions of specific structure weight and specific propulsion system weight. A 10 percent change in structure or propulsion weights can increase costs approximately 5 percent. The

assumed structure specific weight is the least certain of the two. However, vehicle size is not sensitive to assumed weight variations approximating 50 percent. Additional effort in the form of vehicle tests and design studies are necessary and should be accomplished to more precisely define the structural weights of air cushion vehicles.

4. The characteristics and costs of the skirted type vehicles are importantly affected by assumed hydrodynamic drag. Precise definition of appropriate skirt length for obtaining minimum vehicle costs and efficient configuration are dependent on obtaining skirt drag and behavior data. The hydrodynamic drag characteristics of flexible skirt elements should, therefore, be experimentally determined just as rapidly as their basic structural development permits.

5. Air cushion vehicles were found to be significantly affected both in cost and physical characteristics by design operating height. Operation with some wave impact is indicated to be necessary. Determination of minimum wavy water operating height consistent with the operational requirements and maximum vehicle efficiency should be accomplished with tests of an experimental vehicle in realistic LOTS operations. The partially skirted and air wall types were the more sensitive to this parameter and reflect the requirement for determining the proper amount of skirting to be employed. Modest reductions in operating height requirements for all vehicles or further extensions of peripheral jet vehicle flexible skirts could provide significant cost and size reductions.

6. The air cushion vehicles were found to be sensitive to imposed maneuver requirements. Maneuver requirements in excess of .15 'g' causes increases in installed power. The vehicle weight, fuel consumption and cost all increase as a result. It is important, therefore, that reasonable ACV maneuver requirements be established which are not unduly conservative but are consistent with safe, efficient and useful operation of the ACV. Realistic LOTS operation tests with a first generation ACV should be performed to serve as a basis for refinement of the nominal .25 'g' maneuver requirement selected for this study.

(C) SECTION VI

(C) DIRECT OPERATING COST (U)

(C)
A. (U) COSTING METHODOLOGY (U)

(U) Although the relative advantages and disadvantages of a transportation system do not lend themselves to complete quantification, it is desirable to make those quantitative comparisons that are possible. Toward this end the wheeled amphibious and air cushion lighters that are considered applicable to the present study of LOTS operations are placed in a mission environment which allows their costs to be quantified in a manner permitting comparison. Additionally, an advanced helicopter (the Chinook) is included for comparative purposes. Although the following LOTS mission is specific, it is not particularly restrictive and serves the purpose of providing a common reference for vehicle costing.

1. (U) MISSION

One ship hatch is to be kept in constant operation for 20 hours each day. Regardless of the offshore distance, a sufficient number of lighters are provided to load cargo at the rate supplied by the hatch. Lighters are required to carry cargo from the ship to some inland point, and return empty. This operation is assumed to continue for a long unspecified period of time.

It may be noted that this mission represents the maximum system productivity when a given number of ships are being worked, and that the productivity is constrained only by the ship's hatch rate.

It may be shown that the cost of unloading the ship's hatch may be isolated from the system operation. The cost of lighterage required to unload the hatch can be expressed in the form of dollars per ton of cargo transported for a given mission

radius. Any total system may be considered to be a multiple of the above mission with the same cost per ton, and with productivity proportional to the number of hatches being worked. The assumption of a 20-hour day (two shifts of 10 working hours with two one-hour breaks) is consistent with Army planning and minimizes standing equipment costs.

In the framework of this idealized mission the costs associated with each type of lighterage are examined in detail. The costs are expressed in terms of dollars, manpower, fuel, and number of lighters. The lighterage costs discussed here are not system costs, but relative costs which omit components that are common to all lighters.

The lighters considered in addition to air cushion vehicles are the LARC-5, LARC-15, BARC and an advanced helicopter. The helicopter selected for the comparison is the Chinook, now under development by Boeing-Vertol and powered by the two GE T-64 turbine engines. The basic cost and performance data used is from Reference 42 and is felt to represent the costs of a helicopter employing advanced technology typical of the 1965-1970 time period. Conventional landing craft; i.e., LCMs are not included in this study. As discussed in Sections II and III of this report, previous studies (References 5 and 6) have shown that they have the following deficiencies relative to the true amphibians in the LOTS environment:

(1) Over-the-beach operations such as those conducted during WW II, which were characterized by massive cargo loads on the beach, along with the associated large numbers of men and cargo-handling equipment, is an untenable situation in the present-day nuclear environment.

(2) The requirement of on-the-beach cargo transfer and landing craft beach gradient requirements place a greater constraint on the beach to be selected for the operation.

(3) Their manpower costs are always higher (because of the additional cargo transfer on the beach).

(4) Dollar costs are usually higher (due to additional cargo transfer equipment, vehicles and men).

In spite of the fact that the LCMs may be used in future operations simply because they are in the present inventory, the above considerations are deemed to be sufficient to preclude inclusion of their costs and comparison in the present study.

The following notation is adopted in quantitatively stating the costing relationships.

D_w = Offshore (water) distance, nautical miles

D_l = One-way land distance, nautical miles

v_w = Water speed, knots

v_l = Land speed, knots

v_e = Equivalent speed (of helicopter)

$$= 2\left[\frac{1}{v\ \text{loaded}} + \frac{1}{v\ \text{empty}}\right]^{-1}$$

C_{ow} = Cost of lighter while it is operating on the water, \$/Hr

C_{ol} = Cost of lighter while it is operating on land, \$/Hr

C_l = Cost of lighter while it is being loaded at shipside, \$/Hr

C_u = Cost of lighter while it is being unloaded at the inland transfer point, \$/Hr

P = Lighter's payload for a given mission, short tons

P_o = Lighter's payload for a zero-range mission, short tons

H = Ship's hatch rate, short tons/Hr

U = Lighter unloading rate, short tons/Hr

T_d = Delay time each way in the lighter's cycle; i.e., time that the lighter is considered to be operating, but not progressing (not applicable to the helicopter)

T_t = Helicopter transfer time; time for the helicopter to approach, pick-up or release its sling-loaded cargo, and be on its way

F_w = Fuel rate of the lighter on the water, Lb/Hr

F_l = Fuel rate of the lighter on land, Lb/Hr

N = Number of lighters serving a single hatch

A = Availability of lighterage

2. (c) ~~(U)~~ DOLLAR OPERATING COSTS (U)

(U) Lighterage direct operating costs are shown as dollars per ton of cargo delivered, where operating costs are composed of the following components:

(1) Amortization of initial lighter cost

(2) Cost of attrition of lighterage

(3) Cost of lighter maintenance

(4) Lighter fuel cost

(5) Lighter crew cost

The lighter's cycle is divided into five components--water travel, land travel, load, unload and delay. The cost of one complete lighter cycle is then given by

$$C_1 \frac{P}{H} + C_u \frac{P}{U} + 2 \left[C_{o1} \frac{D_1}{v_1} + C_{ow} \frac{D_w}{v_w} + C_{ow} T_d \right]$$

where the notation is as given above, and the delay period is charged at the water operating rate (C_{ow}). The cost per ton is then obtained by dividing the total cycle cost by the payload carried, P.

$$\text{Cost/ton delivered} = \frac{C_1}{H} + \frac{C_u}{U} + \frac{2}{P} \left[C_{o1} \frac{D_1}{v_1} + C_{ow} \frac{D_w}{v_w} + C_{ow} T_d \right]$$

It is assumed that the helicopter carries its cargo as an external sling load, and that it hovers while picking up and releasing its cargo. Under these circumstances, the helicopter is assumed to remain airborne throughout the cycle, and the operating costs are, therefore, chargeable at a constant rate per unit of cycle time. It is further assumed that a sling load of cargo is awaiting the helicopter as it approaches the ship and that pickup of this cargo is made by the helicopter in time T_t without interference with the ship's boom operation. The helicopter likewise is assumed to discharge its cargo load at the inland cargo transfer point in time T_t. These features of helicopter operation as set forth in the above assumptions require a costing equation different from that used for the amphibious lighters. Cycle time is expressed by the following equation:

$$\text{Cycle time} = 2 \left[T_t + \frac{D_w + D_1}{v_e} \right]$$

The helicopter delivers payload P each cycle with cycle time chargeable at the rate of C_{o1} dollars per hour. The direct operating cost is then represented by:

$$\text{Cost/ton delivered} = \frac{2C_{o1}}{P}\left[T_t + \frac{D_w + D_1}{v_e}\right]$$

Individual terms of these equations are discussed in detail below.

a(C) <u>Distances, Speeds</u> (U)

The nominal LOTS mission distances of applicability as previously discussed in Section III of this report are 0 to 75 nautical miles offshore and 0 to 10 nautical miles inland. The costing results are shown in the following report sections as a function of these distances. The speeds used are the nominal vehicle speeds for the specified conditions. As will be shown later the amphibious vehicles are costed under various inland terrain conditions with corresponding on-land speeds and operating costs.

The speed of the helicopter is obviously not affected by the presence of land or sea environments. The speed used for the helicopter is actually an equivalent speed, since it is assumed that the cargo load is carried externally; and that the loaded speed is limited by the sling carried cargo (Reference 35). The helicopter equivalent speed is given by

$$\frac{2}{v_e} = \frac{1}{v_{loaded}} + \frac{1}{v_{empty}}$$

b.(U) <u>Delays in the Lighter Cycle</u>

As used here, the delay time refers to the time that the lighter may be considered to be operating but making no forward progress. Delays arise from a number of sources as discussed in Section V of this report. Possible sources of delay are again enumerated here for completeness.

Slow down on approaching ship
Queuing at the ship
Approach and cast-off
Accelerate to speed

Cross the surfline
Negotiate the beach
Negotiate obstacles
Maneuver at intransit point
Queuing at intransit point

The first three items have been treated in detail in Reference 5 and queuing was found to be particularly significant. Queuing, as previously indicated in Section V and shown in the cited Reference, can be treated analytically but only by defining the system operation more completely than permitted by the generalized situation now under consideration.

Rigorous treatment of the queuing problem requires that a specific situation be dealt with and that the influences of environment, command and control systems and other situation factors which influence the random fluctuations that take place in an actual system be considered.

Therefore, queuing is included only in that it may be considered to contribute a fixed delay time to the cycle and to be included in T_d. Based upon data from ORO T-361 and estimated values, the delays in a lighter cycle are assumed to be:

Queuing at ship	6 minutes
Tie-up and cast-off	5 minutes
Negotiate surf	3 minutes
Negotiate obstacles at inland transfer	2 minutes
	16 minutes

or eight minutes each way. The half-cycle delay time, T_d is then equal to 0.135 hours. Since the delay time tends to occur in the overwater portion of the mission, this time is charged at the overwater operating cost and fuel rates.

For the helicopter, the delay time is assumed equal to zero since approach, etc., have been included in the transfer time T_t.

c. (U) Cargo-Handling Rates

Cargo-handling rates, as indicated in Section III of this report, are heavily dependent upon the cargo type. The applicable 1965 to 1970 nominal shipside and inland cargo handling rates are approximately 15 and 20 tons per hour, respectively, and are the nominal values used herein. The effect of cargo-handling rate variations upon lighterage costs are shown. Reference 5 also shows that hatch rate is virtually independent of the lighter type when unloading is accomplished in favorable environments.

In the case of the helicopter, it is generally desirable to handle cargo with an external sling for short missions, and load it internally for long-range missions (Reference 36). However, for the LOTS mission, the helicopter will be assumed to be constrained to external loading, since facilities for landing and internally loading are not normally available on conventional MSTS and commercial shipping. Helicopter pickup of external loads from this class shipping has been demonstrated in Project Mobility although the practicality of adopting such a method to a full-scale logistics mission is not clear at this time. It is assumed herein that the sling-transfer can be made, and that there is no interference between the helicopter and the ship's boom. The time for the transfer to occur, T_t, is shown in Reference 1 (FM-101-10) to be about four minutes, or .0667 hours. This value is used for both the cargo pickup and release operations performed by the helicopter.

Examination of the typical normal ships hook cycle time given by Reference 5 indicate that between 1/2 and 1/3 of this time might be eliminated by depositing the cargo directly upon any assumed convenient deck space (eliminating deposit-in-lighter portion of the hook cycle). However, preparing the cargo for helicopter pickup is assumed to negate any gain in hatch rate resulting from reduction in the hook-cycle time. The same hatch rate as used for the amphibians is, therefore, used with the helicopter. The unloading rate is automatically specified by the transfer time T_t.

d.(U) Payload

Since relatively long mission ranges are considered, it is necessary to consider changes in payload with mission distances. The payload variation with range is estimated by assuming a fuel consumption independent of gross weight. For surface and waterborne vehicles the estimation procedure results in accurate payload-range predictions since the propulsive requirement is not significantly affected by weight changes of the magnitude produced by burning off fuel. Due to the characteristics of the ACV and the turbine powerplants characteristic of increased specific fuel consumption at partial powers, the linearized payload-range estimation procedure also results in good estimation at the ranges considered for the ACVs.

The linear payload-range relationship for the helicopter is taken from Reference 42 with the fuel reserve and headwind allowance omitted.

As required by the air cushion vehicles, allowance is made for a different fuel consumption on land than on water. For purposes of estimating payload at varying ranges, no allowance is made for fuel consumed while the lighter is being loaded at shipside. The lighter's payload is then given by

$$P = P_o - \frac{2}{2,000}\left[F_w \frac{D_w}{V_w} + F_1 \frac{D_1}{V_1} + F_w T_d\right]$$

The delay time is charged with the overwater fuel rate. Refueling every trip is implied in this method, and it is presumed that this is accomplished at the inland transfer point without detracting from the cargo-handling process. It is realized that fueling while unloading is presently considered to be hazardous operating procedure. However, the use of single-point pressure-feed fueling and proper operating procedures should result in safe refueling and keep delays to a minimum. Current civil airline practices embody this concept of operation and demonstrate enviable safety records in this respect.

As discussed in Section III, certain of the lighters are often unable to carry their rated tonnage of typical military cargo because of space limitations. Therefore, costs are shown for the space-limited payloads as well as the vehicle's maximum rated payloads discussed above. Note that for long-range missions the payload may be limited by fuel requirements rather than cargo-stowage space.

e.(U) Amortization Cost

The initial cost of amphibious vehicles is taken from available references and, for consistency, corrected to a total production of 500 units. The correction is accomplished with an 85% learning curve (Reference 37). Unfortunately, the initial cost data available on existing wheeled amphibians and helicopters is not, in all cases, qualified as to quantity, development costs, etc. Reducing the initial costs of vehicles to a common base remains, therefore, a "best estimate." However, cross-checking of data obtained from several sources for a particular vehicle indicates good agreement.

Standard military practice is to amortize the initial cost of a vehicle over a given number of years (usually three) (References 5 and 6) regardless of the actual vehicle life or the number of hours it is actually operated. That is, time-wise rather than operation-wise depreciation is assumed.

The mission now under consideration, however, is a sustained military operation with maximum possible utilization of all vehicles. In this situation it is felt that the number of operational hours, rather than the simple passage of time, will determine the depreciation of the vehicle. No salvage value is assumed, and the hourly amortization charge is found by dividing the initial cost by the assumed vehicle life in hours.

f.(U) Maintenance Cost

The maintenance cost per vehicle operating hour was computed as the percentage of initial cost annually expended for maintenance; divided by the hours per year that the vehicle is utilized. The annual costs for existing lighterage vehicle maintenance and their annual utilization were correlated in terms of vehicle initial costs from available data (References 33).

Note that the percentage of initial cost per year is relatively meaningless unless the annual utilization is specified concurrently. Therefore, although the maintenance percentages used herein are considerably higher than may be found elsewhere (Reference 5), the annual utilization is correspondingly higher and the hourly maintenance charge is comparable and representative of the vehicle considered.

g.(U) Attrition Cost

The attrition cost is the cost of replacing vehicles that are damaged beyond economical repair. The cost of this is extracted from available data in the same form as maintenance; i.e., as a percentage of the initial vehicle cost per year, or percentage of force lost per year. The hourly attrition cost is given by

$$\text{Attrition cost} = (\text{initial cost}) \times \frac{\text{attrition rate/year}}{\text{utilization hours/year}}$$

It may be noted that maintenance cost and attrition cost enter the calculation in exactly the same way and are interchangeable. Thus a maintenance charge of 50 percent and an attrition charge of 5 percent of initial cost per year is equivalent to any combination of these two cost components that adds up to 55 percent.

h.(U) Fuel Cost

The land and water fuel consumptions, given in pounds per hour are obtained from available performance data, and this fuel is then costed in the following manner as a function of the type of fuel used by the lighter:

Type Fuel	Cost,* ¢/lb
Gasoline	2.9
Diesel fuel	1.34
JP 4	2.0

*Reference 33

i.(U) Crew Costs

In cases where available data specified lighter crew costs in dollars per operational hour, values thus obtained were used. Where data was not available, the size of the crew was estimated and costs charged at $1.43 per operational hour or $14.30 per 10-hour working day. These crew cost charges are those commonly used for enlisted personnel (Reference 5).

j.(U) Operating Cost

The total operating cost per hour is the sum of amortization, attrition, maintenance, fuel and crew costs as discussed above. The crew and attrition costs are assumed to be independent of operating terrain and are the same on land as on the water. The useful life (and, therefore, amortization cost), the maintenance cost, and fuel cost are evaluated separately for land and water operation, resulting in overland and overwater operating costs, of C_{ol} and C_{ow} respectively.

k.(U) Cost of Lighter While Unloading, C_u

It is assumed that while an amphibious lighter is being unloaded it

(1) does not depreciate,

(2) does not become damaged, so as to require maintenance

(3) uses no fuel,

(4) is not destroyed, and

(5) requires its normal crew.

The hourly cost during this period is, then, simply the hourly cost of the crew.

Since the helicopter is hovering while unloading, the cost during unloading is the same as the operating cost.

l.(U) Cost of Lighter While Being Loaded, C_l

Because of buffeting by waves, possible contact with the ship, and impact with the cargo, it is assumed that an amphibious vehicle is just as likely to be lost, damaged, or worn out when it is being loaded as when it is under way. Therefore, all normal operating costs, except fuel consumption, are assumed to continue during this time. To allow sufficient power expenditure to maintain control at shipside, fuel cost is calculated at 10 percent of that while under way on the water.

Since it is assumed that the helicopter picks up its load on a sling, it is hovering during this time, and the cost is the same as the operating cost.

3 (U) NUMBER OF LIGHTERS

Although the previously discussed direct operating cost inherently accounts for the amortization of the proper number of lighters, it is of value to examine this number independent of cost. The number of lighters is of interest for examining the procurement cost and the cost of lighter transhipment.

Per the defined mission, the unloading of one ship hatch is considered, and the number of operating amphibious lighters is constrained by the requirement that one be at shipside at all times. This number is then given by

$$N = \frac{\text{cycle time}}{\text{loading time}}$$

where

$$\text{Cycle time} = \frac{P}{H} + \frac{P}{U} + 2\left[\frac{D_w}{v_w} + \frac{D_1}{v_1} + T_d\right].$$

Notation is as given previously.

Since sling loading of the helicopter is assumed, a helicopter need not be at the hatch while its sling load is being prepared, and it must repeat its cycle only often enough so that H tons of cargo are received per hour; i.e., so that

$$\frac{PN}{\text{cycle time}} = H.$$

Since the cycle time of the helicopter is,

$$2\left[T_t + \frac{D_1 + D_w}{v_e}\right],$$

the number of operating helicopters required to service one ship hatch is

$$N = 2\frac{H}{P}\left[T_t + \frac{D_w + D_1}{v_e}\right],$$

To keep these N lighters operating on a continuous basis, N/A lighters must be maintained in the operations theater, where A is defined as

$$A = \frac{\text{number of operating lighters}}{\text{number of lighters in the theater}}$$

4.(U) PROCUREMENT COST

Even though amortization of the initial lighter cost was includ d in the operating cost given previously, it is useful to make a separate comparison on the basis of procurement cost. The comparison will be made by use of the parameter dollars per ton per hour as a function of mission radius; i.e., the cost or procuring a sufficient number of lighters to transport cargo at a given rate over a given distance. The value of this parameter lies in the fact that it is directly related to the impact on the national budget for procuring a desired lighterage capacity. It is also indicative of the cost of maintaining a given lighterage capacity in the peacetime inventory.

The cost of procuring the lighterage required to sustain the specified hatch rate is obtained from the expression

$$\text{procurement cost} = \frac{\text{initial cost}}{A}\left[\frac{1}{H} + \frac{1}{U} + \frac{2}{P}\left(\frac{D_w}{v_w} + \frac{D_1}{v_1} + T_d\right)\right]$$

for amphibians, and

$$\text{procurement cost} = \frac{\text{initial cost}}{A}\left[\frac{2}{P}\left(T_t + \frac{D_w + D_1}{v_e}\right)\right]$$

for helicopters. Note that the helicopter procurement cost is not affected by hatch rate, since its loading time is independent of hatch rate.

5.(C) MANPOWER REQUIRED (U)

The operating costs shown previously included an estimated cost of the lighter operating crews. It is evident, however, that situations may arise in which manpower is at a premium, and the dollar cost per se becomes relatively meaningless if the manpower to conduct the operation is not available. Therefore, a direct measure of the required manpower was computed. Basic data for the LARC-BARC amphibious family were used as a basis for the manpower estimates.

In general, a lighter may be considered to require S man hours of maintenance and support for each operational hour, in addition to the man hours expended by the operating crew, C. Based upon Transportation Amphibious Company TOE personnel (References 38, 39 and 40) and planning data from FM 101-10, the following values for these parameters are used:

	LARC-5	LARC-15	BARC	Helicopter
S $\frac{\text{man-hours}}{\text{hours}}$	1.02	1.46	3.61	34
C $\frac{\text{man-hours}}{\text{hours}}$	2	2	4	3

Comparison of these data with data on vehicle initial costs in Figure VI-1 discloses an empirical relationship in the ratio of

$$S = 28 \times 10^{-6} \times \text{(initial cost)}.$$

This then provides a correlation to use in estimating the manpower required for the selected air cushion vehicles, for which data is not available.

Since the selected air cushion vehicles have payloads of 15 tons or less, they are assumed to have a crew of two.

The number of man-hours per ton of cargo delivered may be shown to be

$$= (S + C)\left[\frac{1}{H} + \frac{2}{P}\left(\frac{D_w}{v_w} + \frac{D_1}{v_1} + T_d\right)\right] + \frac{C}{U}$$

for amphibians.

For the helicopter man-hours per ton of cargo delivered becomes

$$= (S + C)\left(\frac{2}{P}\right)\left[T_t + \frac{D_w + D_1}{v_e}\right]$$

in as much as maintenance hours are accrued during both loading and unloading periods (hovering).

6. (U) FUEL COST

The actual dollar cost of fuel consumed by lighterage in a particular military situation may be of little importance. However, the amount of fuel required for any lighter may be readily ascertained and used directly as a performance criterion. The pounds of fuel used by an amphibian per ton of cargo delivered is given by

$$\text{fuel/ton} = F_w\left[\frac{1}{10H} + \frac{2}{P}\left(\frac{D_w}{v_w} + \frac{D_1}{v_1} \cdot \frac{F_1}{F_2} + T_d\right)\right]$$

where the fuel consumption in pounds per hour is F_w on the water, F_1 on land, and $F_w/10$ while at shipside.

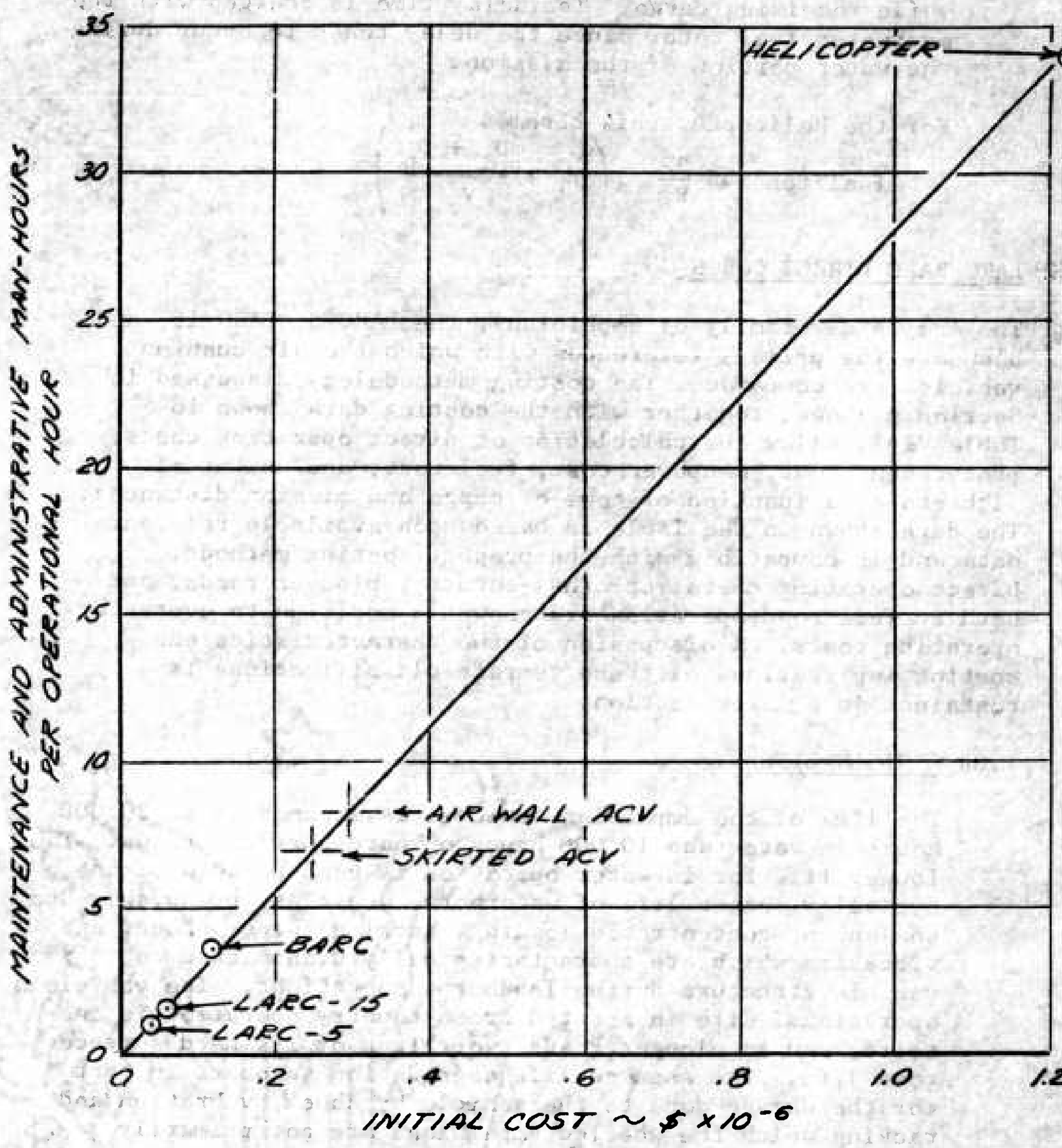


Figure VI-1. (C) Correlation of Man Hours Required for Maintenance and Support. (U)

As discussed previously, the shipside fuel consumption (F_v/10) is assumed to allow the lighter to maintain control while receiving cargo. The delay time is charged with the overwater fuel rate, since the delay tends to occur during the water portion of the mission.

For the helicopter this becomes

$$\text{fuel/ton} = \frac{2F}{P}\left(T_t + \frac{D_1 + D_w}{v_e}\right).$$

B. ~~(U)~~ (C) <u>LARC-BARC DIRECT COSTS</u> (U)

(U) The Army's new family of amphibians, the LARC-5, LARC-15, and BARC are the primary references with which the air cushion vehicles are compared. The costing methodology discussed in Section A above, together with the costing data shown in Table VI-I, allow the calculation of direct operating costs, procurement cost, manpower cost, fuel cost, and number of lighters as a function of tons of cargo and mission distances. The data shown in the Table is based upon available reference data and is compatible with the present costing methods. Direct operating costs for cross-country, pioneer roads, and hard surface road operation are shown in addition to overwater operating costs. A discussion of the characteristics and costing implications of these terrain classifications is contained in a later section.

1. (U) <u>VEHICLE LIFE</u>

The life of the amphibian vehicles is assumed to be 20,000 hours in water and 10,000 hours on hard-surfaced roads. The longer life for in-water operation is used because of the typically longer life of waterborne vehicles, presumably due to lack of concentrated loading, racking loads, shock, and vibration which are characteristically transmitted to vehicle structure during landborne operations. The vehicle's operational life in scouted cross-country operation is one-third, and on pioneer roads two-thirds of its hard surface road life. The assumed life degradation accounts in part for the damage done to the vehicle by shock, vibration and racking which the wheeled amphibians are not primarily intended to withstand.

TABLE VI-1
(C) LARC-BARC COSTING DATA* (U)

	LARC-5	LARC-15	BARC
Initial cost, dollars	33,900	60,000	116,000
Life, hour			
water	20,000	20,000	20,000
cross-country	3,333	3,333	3,333
pioneer road	6,667	6,667	6,667
hard road	10,000	10,000	10,000
Annual maintenance rate, % initial cost			
water	50	50	50
cross-country	150	150	150
pioneer road	100	100	100
hard road	50	50	50
Attrition rate, %	5	5	5
Utilization, hour/year	4,750	4,750	4,750
Fuel rate, pound/hour	118	235	255
Operating cost, dollars/hour			
water	11.00	20.00	26.40
cross-country	26.60	47.60	79.90
pioneer road	17.90	32.20	50.30
hard road	12.70	23.00	32.20
Unload cost, dollars/hour	2.00	3.00	3.80
Load cost, dollars/hour	8.00	13.70	23.40
P_o - maximum payload, s. tons	5.40	16.20	61.8
- space limited, s. tons	4.50	10.2	30.0
Speed, knots			
water	7	7	6
cross-country	4	4	3
pioneer road	8	8	6
hard road	17	13	9
Availability, %	80	80	80

*See text for references.

2. (U) UTILIZATION, INITIAL COST

The annual utilization used for the wheeled amphibians is based upon an average operating time of 13 hours per day. Planning factor operational cycles and the availability of 80 percent cited in the applicable TO & E's (References 38, 39 and 40) were used in obtaining the average 4750 hours per year utilization. The initial costs were taken from References 6 and 33, and for consistency corrected to a total production of 500 units. The resulting initial costs are shown in Table VI-1.

3. (U) MAINTENANCE

The maintenance costs for amphibious vehicles were primarily obtained from Reference 33 which gives maintenance cost in dollars per operational hour and support cost in dollars per year. These two components, which were taken to represent overwater operation, were combined and expressed as a percentage of the initial cost per year using an annual utilization of 4750 hours. On this basis, the annual maintenance cost for each vehicle is approximately 50 percent of the initial cost, and for consistency 50 percent was used for all amphibians considered. The maintenance cost was increased for cross-country or pioneer road operation as indicated in Table VI-1 for the reasons previously stated.

4. (U) ATTRITION, FUEL, PAYLOAD

The attrition rate is taken to be 5 percent per year as estimated by Reference 35. Fuel consumption and payloads are from Reference 34. Fuel rate in pounds per hour is taken to be the same regardless of the terrain limited speed, since it is assumed that difficult terrain travel will cause much acceleration and deceleration. Typical payload specifications for amphibians show a rated payload with a given weight of fuel on board; in the present analysis this fuel weight is added to the rated payload to obtain the zero-radius payload, P_o. The space-limited payloads were obtained from Section III of this report and References 38, 39 and 40.

5.(U) SPEED

Inasmuch as vehicle speeds are an important input to the costing, it is unfortunate that more detailed data is not available for estimating the wheeled amphibian's speed with varying terrain. The operating water speed is taken to be approximately one knot less than the rated maximum water speed. The speed degradation accounts for operation is seas characterized by 3.5 foot significant waves. The cross-country speed is estimated to be that which can be reasonably expected in unprepared terrain and is predicated upon conventional truck-type vehicle experience. The pioneer road speed is assumed to be twice the cross-country value. The hard road speed is assumed to be approximately five miles per hour less than the vehicle's maximum rated land speed.

C.(C) HELICOPTER COSTS (U)

The costing data for the selected (Chinook) helicopter is shown in Table VI-2. The principal costing and performance data are taken from Reference 42 and is felt to reflect advanced helicopter technology. The payload shown in Table VI-2 does not include allowance for head winds or a fuel reserve, but does allow fuel for hover during picking up and releasing the cargo sling.

The annual utilization is based upon four hours operation per day as given by References 1 and 41 (FM-101-10 and LOGX-61). This utilization corresponds very closely to current commercial helicopter airline experience. In estimating the availability for the helicopter, the four hours per day was increased by 50 percent to allow for increased reliability in the 1965-1970 time period and for an expected decrease in maintenance requirements associated with use of turbine powerplants. The resulting availability, based on a 20 hour working day is

$$\frac{(1.5) \quad (4)}{20} = 30\%.$$

The vehicle life is estimated to be 10,000 hours and corresponds closely to the seven years and the 1500 hours per year utilization presented in Reference 42.

The attrition rate of 15 percent and the 75 knot airspeed with a loaded sling are from Reference 35.

The resulting helicopter costs are somewhat optimistic with respect to current experience but are assumed achievable with the future equipment of the 1965-1970 time frame.

The crew costs are based upon a typical Army helicopter crew, consisting of a Captain, a Warrant Officer, W-1, and a Corporal as given in Reference 43.

TABLE VI-2

(C) HELICOPTER COSTING DATA (U)

Initial cost, dollars	1,230,000
Useful life, hours	10,000
Maintenance cost, dollars/hour	215
Attrition rate, percent/year	15
Utilization, hours/year	1,500
Fuel rate, pounds/hour	2,130
Operating cost, dollars/hour	519
Unloading cost, dollars/hour	519
Loading cost, dollars/hour	519
Zero-radius payload, short tons	5.86
No sling speed, knots	160
Loaded external sling speed, knots	75
Equivalent speed, knots	102
Availability, %	30
Crew cost, dollars/hour	15

D.(U) SELECTED AIR-CUSHION VEHICLE COSTS

The methods and assumptions used in generating performance and costing parameters of air cushion vehicles is discussed in detail in Section V. In that Section, two air cushion vehicles were selected from the optimization procedure--a partially skirted air wall vehicle and a fully skirted vehicle. Table VI-3 shows the costing parameters of the selected vehicles in the form required to permit their comparison with the wheeled amphibians and the helicopter. The maintenance and attrition rates, life, utilization, and availabilities are assumed to be the same as those of the wheeled amphibians. The other costing parameters are based upon assumptions and data generated and discussed in Section V.

TABLE VI-3

(U) AIR CUSHION VEHICLE COSTING DATA

	AIR-WALL VEHICLE	SKIRTED VEHICLE
Initial cost, dollars	253,400	247,000
Life, hours	10,000	10,000
Maintenance rate, % initial cost/yr	50	50
Attrition rate, % initial cost/year	5	5
Utilization, hours/year	4,750	4,750
Speed, knots		
water	80	40
scouted cross-country	15	15
pioneer road	35	35
Fuel rate, pounds/hour		
water (3.5 foot significant waves)	1,645	2,015
scouted cross-country	1,070	945
pioneer road	1,050	990
Operating cost, dollars/hour		
water	88	94
scouted cross-country	75	73
pioneer road	76	74
Unloading cost, dollars/hour	2.86	2.86
Loading cost, dollars/hour	58.20	57.56
P_o, zero-range payload, s. tons	11.29	17.20
Availability, %	80	80

E.(U) DIRECT COSTING RESULTS

The direct costs in terms of dollars, fuel, manpower and number of lighters are shown for the wheeled-amphibian family, the helicopter and the selected air cushion vehicles on Figures VI-2 through VI-13. These Figures show the comparative costs of the selected vehicle as a function of offshore distance. Inland distances to 10 nautical miles and operations over pioneer roads and over scouted cross-country routes are shown. Unless otherwise noted, the wheeled amphibians are given credit for their maximum rated payloads. In the Figures so designated, the payloads of the wheeled amphibians are reduced to account for their space limitations as discussed in Section III.

1.(U) DIRECT OPERATING COST

Figures VI-2 through VI-9 show the lighterage direct operating costs for varying terrain conditions. In general, it may be said that either of the selected air cushion vehicles is economically competitive with the best existing lighterage systems under any of the conditions studied.

It may be deduced from the curves that transport economy can be achieved by either high speed or by large payloads as illustrated by the air cushion vehicles and the BARC. (Economy provided by large payloads can be further illustrated by ocean ships or barges, but such considerations are immediately out of context because these forms of transport are not amphibious.) In addition to the problems associated with making large vehicles amphibious, larger lighters are not necessarily more economical in the relatively short missions with their relatively long standing (loading and unloading) times. Indications are that the BARC's payload is as large or possibly larger than the most economical payload for wheeled amphibious vehicles and for the mission being considered.

The selected air cushion vehicles are sized for minimum cost in their assigned (LOTS) mission. For very short missions, the higher loading and unloading costs of the air cushion vehicles cause them to be slightly more expensive to operate than the wheeled amphibians. For short (5 nautical miles) missions, economics would indicate use of a smaller air cushion vehicle than those selected. The selected vehicles, however, are competitive with wheeled amphibians and at radii greater than about 20 nautical miles are economically superior, hence their speed can be used to advantage.

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE - 0 NAUTICAL MILES

HATCH RATE = 15 S. TONS/HR.
UNLOADING RATE = 20 S. TONS/HR.

—— - —— SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE
— — — — AIR WALL VEHICLE - 3 FT. GROUND CLEARANCE WITH 1 FT. FLEX. SKIRTS

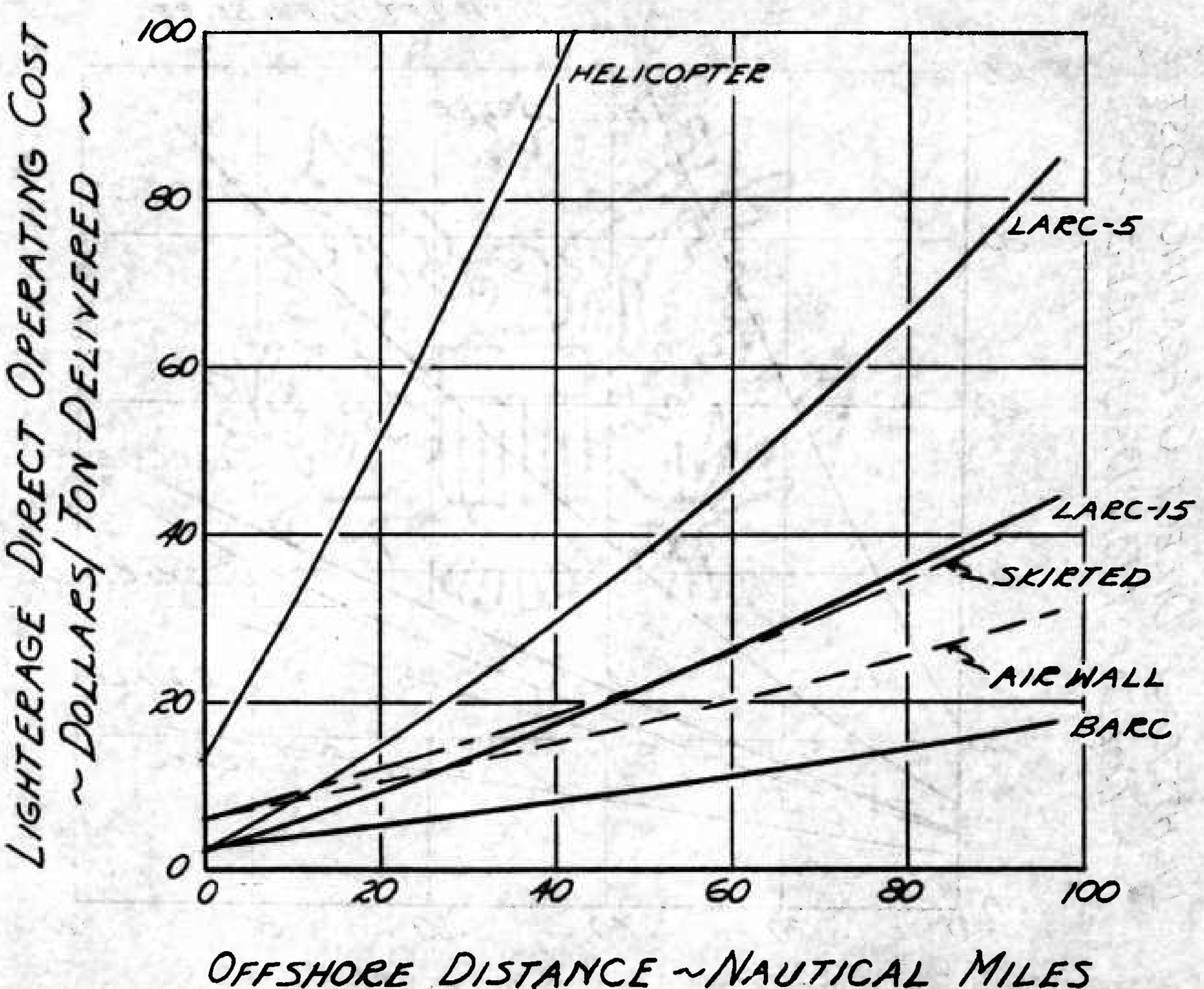


Figure VI-2

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE = 5 N. MI., CROSS COUNTRY

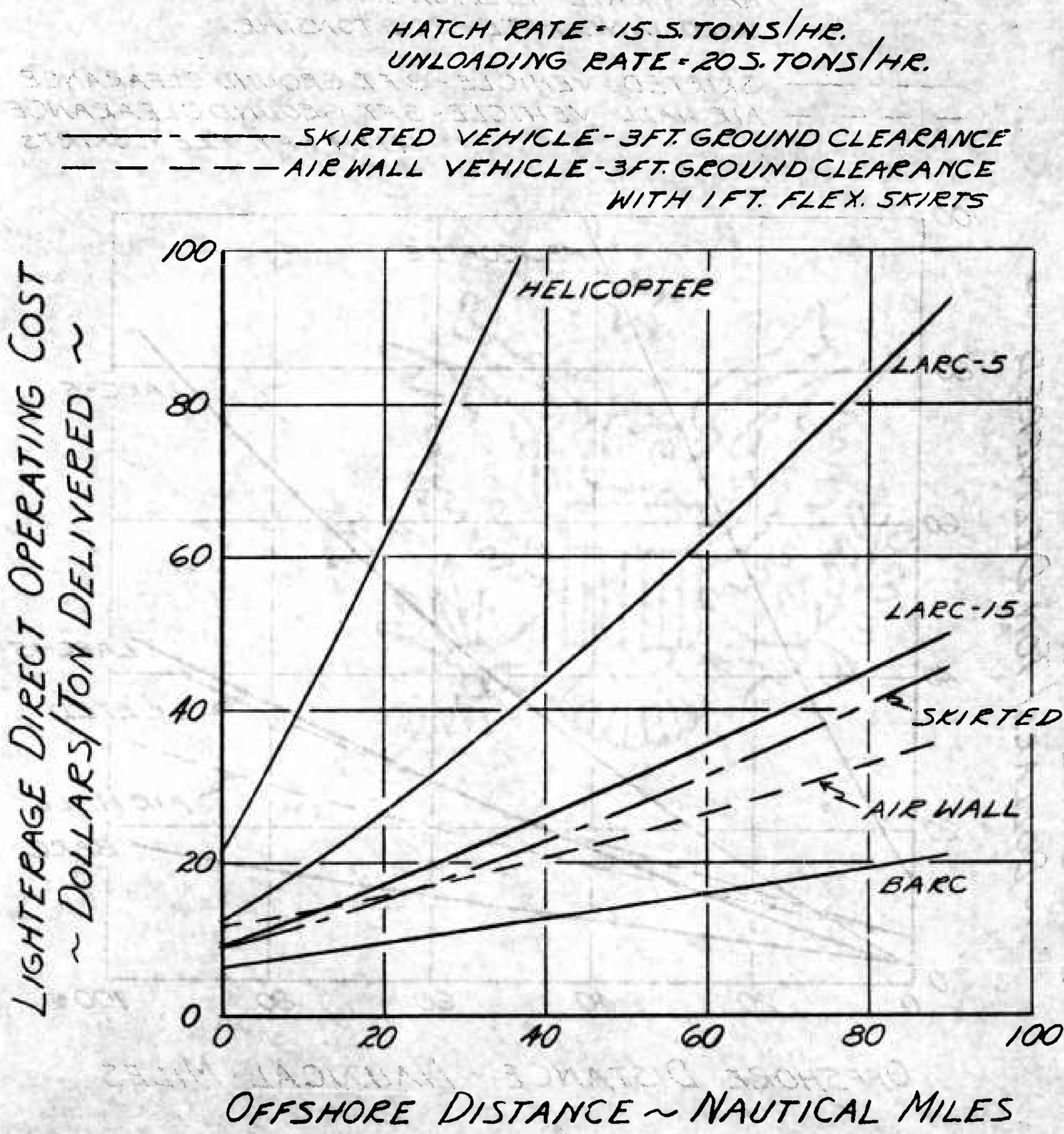


Figure VI-3

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE = 5 N.MI., PIONEER ROAD

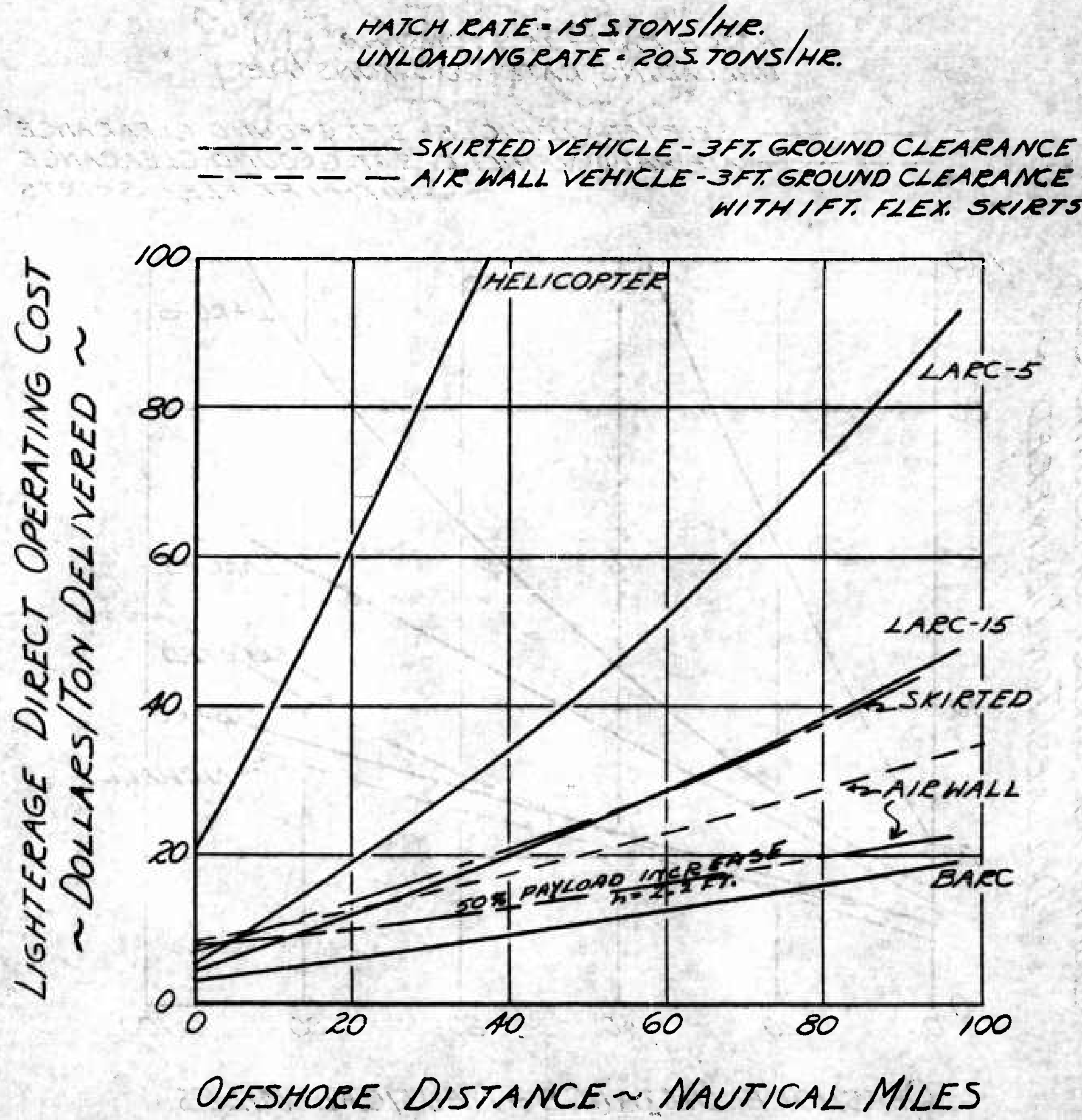


Figure VI-4

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE - 5 N.MI., CROSS-COUNTRY
WHEELED AMPHIBIAN VEHICLES SPACE LIMITED

HATCH RATE = 15 S. TONS/HR.
UNLOADING RATE = 20 S. TONS/HR.

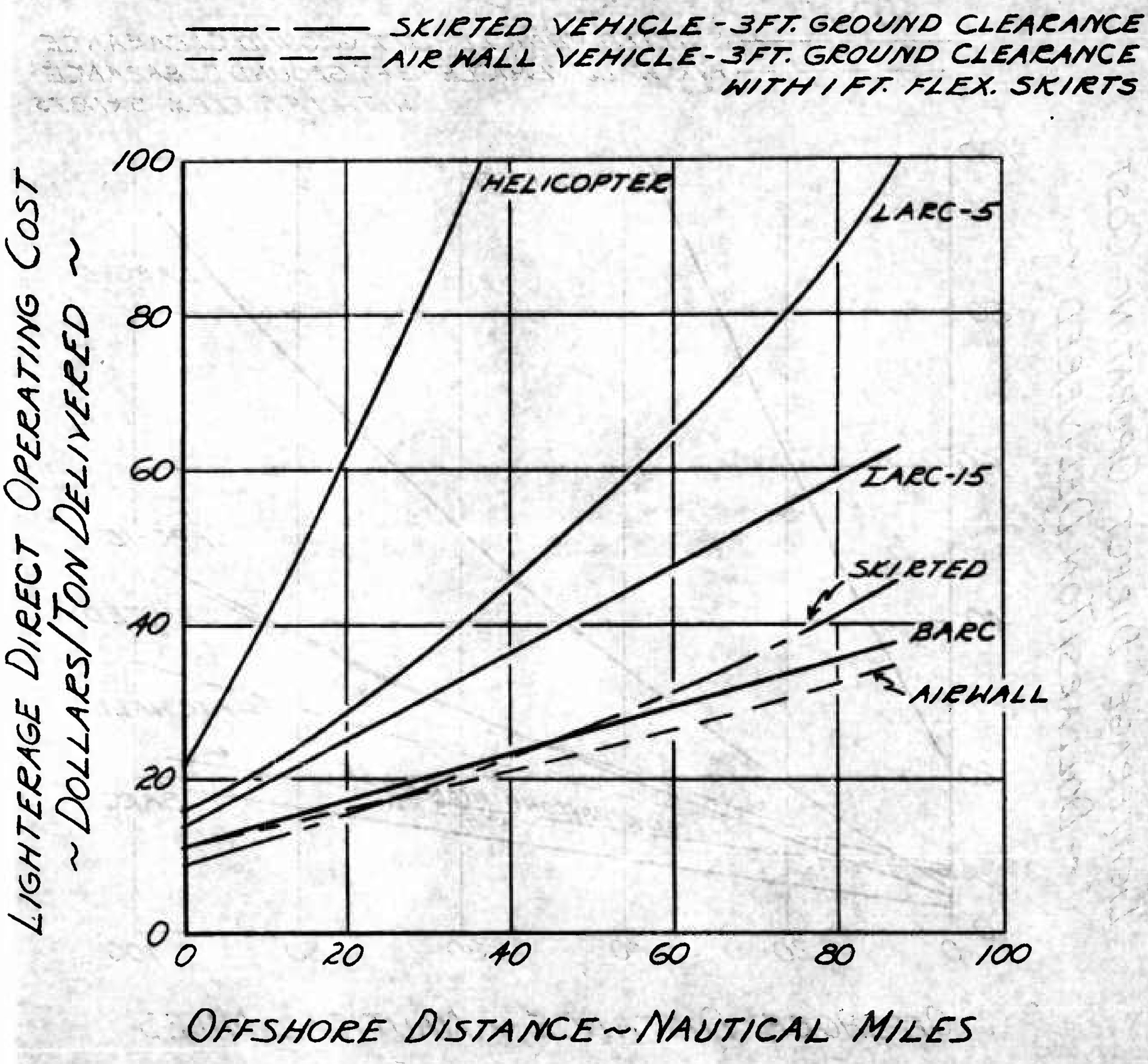


Figure VI-5

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE = 5 N. MILES, PIONEER ROAD
WHEELED AMPHIBIAN VEHICLES SPACE LIMITED

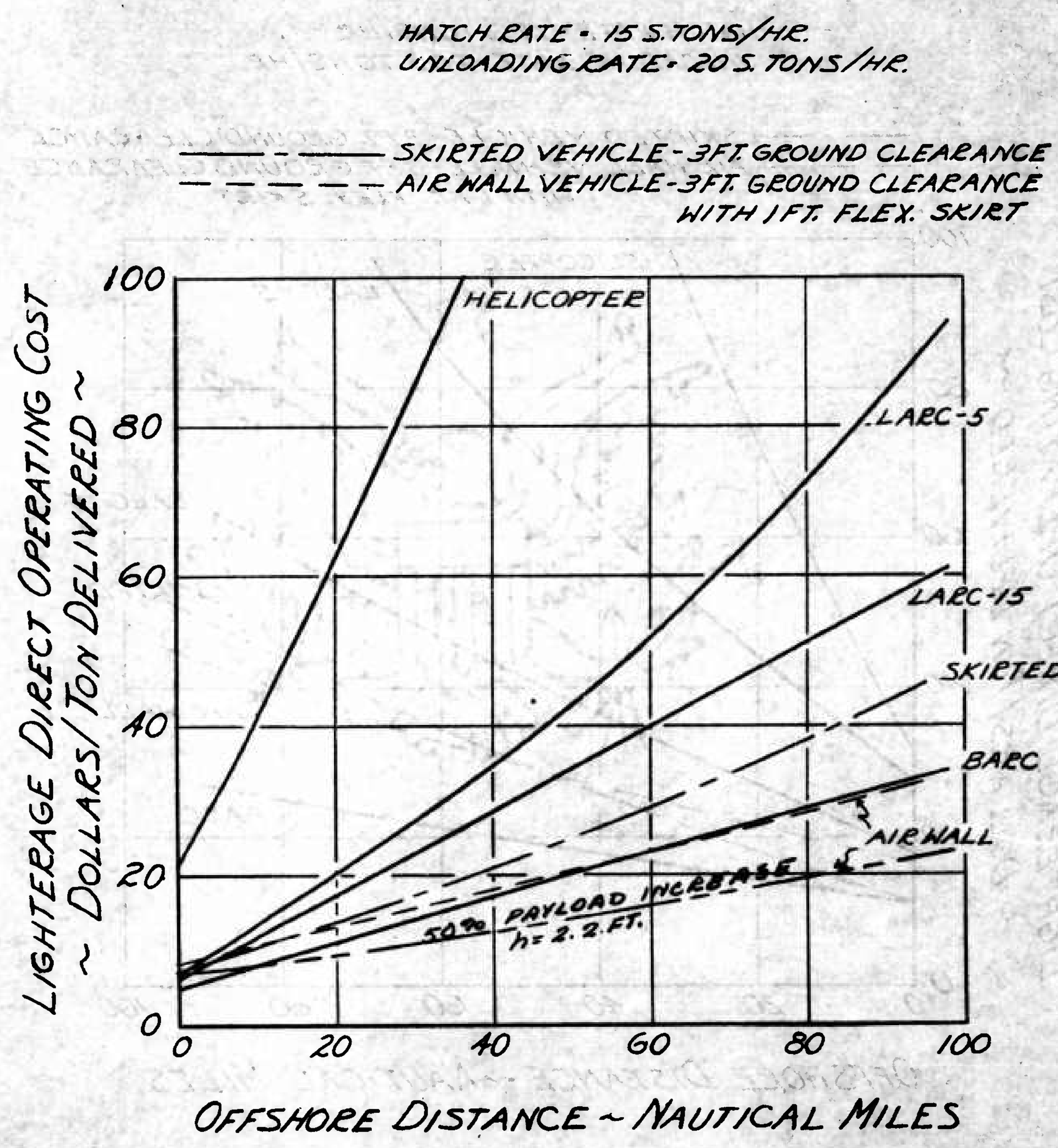


Figure VI-6

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE = 10 N.MI., CROSS COUNTRY

HATCH RATE = 15 S. TONS/HR.
UNLOADING RATE = 20 S. TONS/HR.

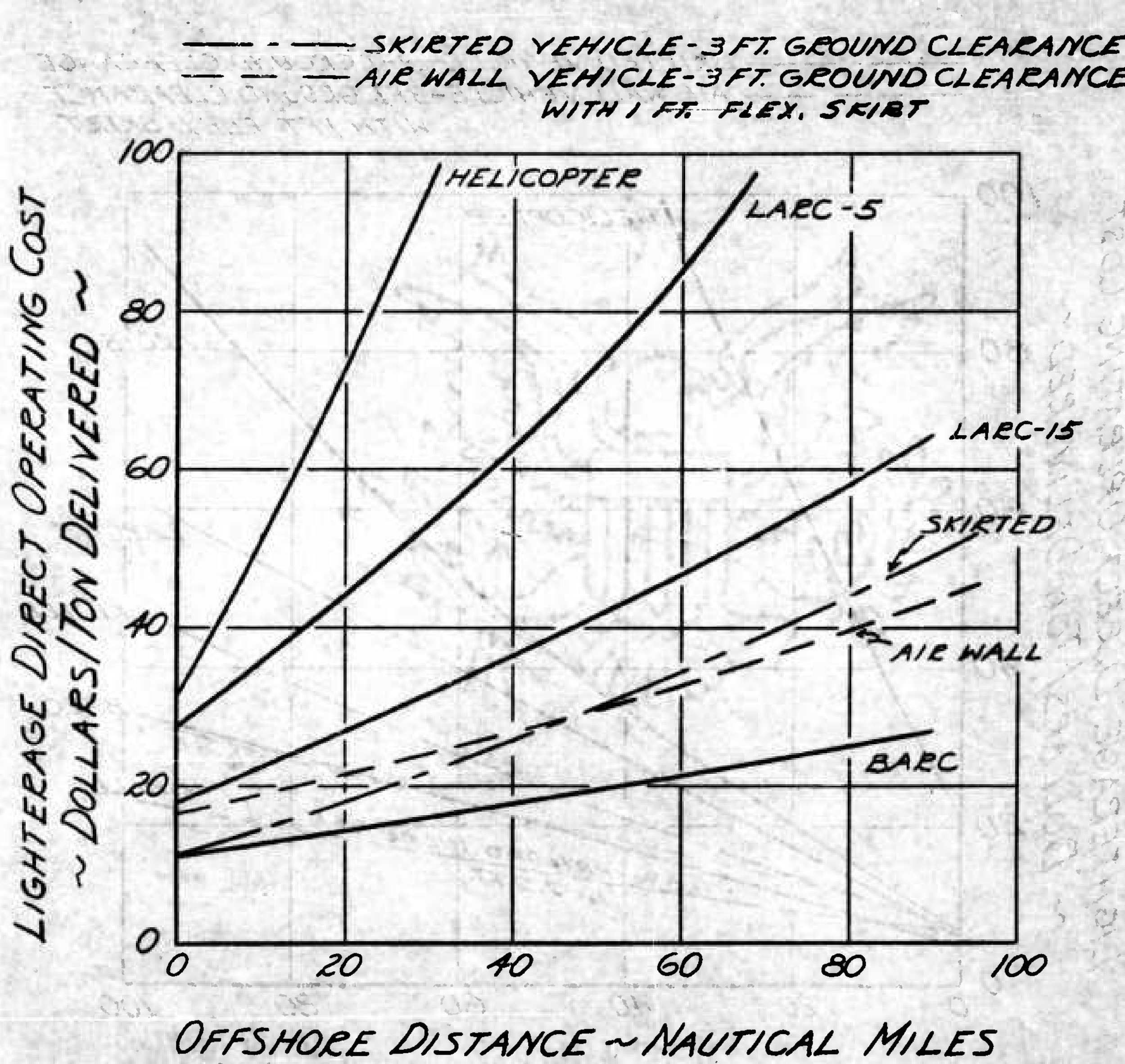


Figure VI-7

(U) LIGHTERAGE DIRECT OPERATING COST INLAND DISTANCE = 10 N.MI., PIONEER ROAD

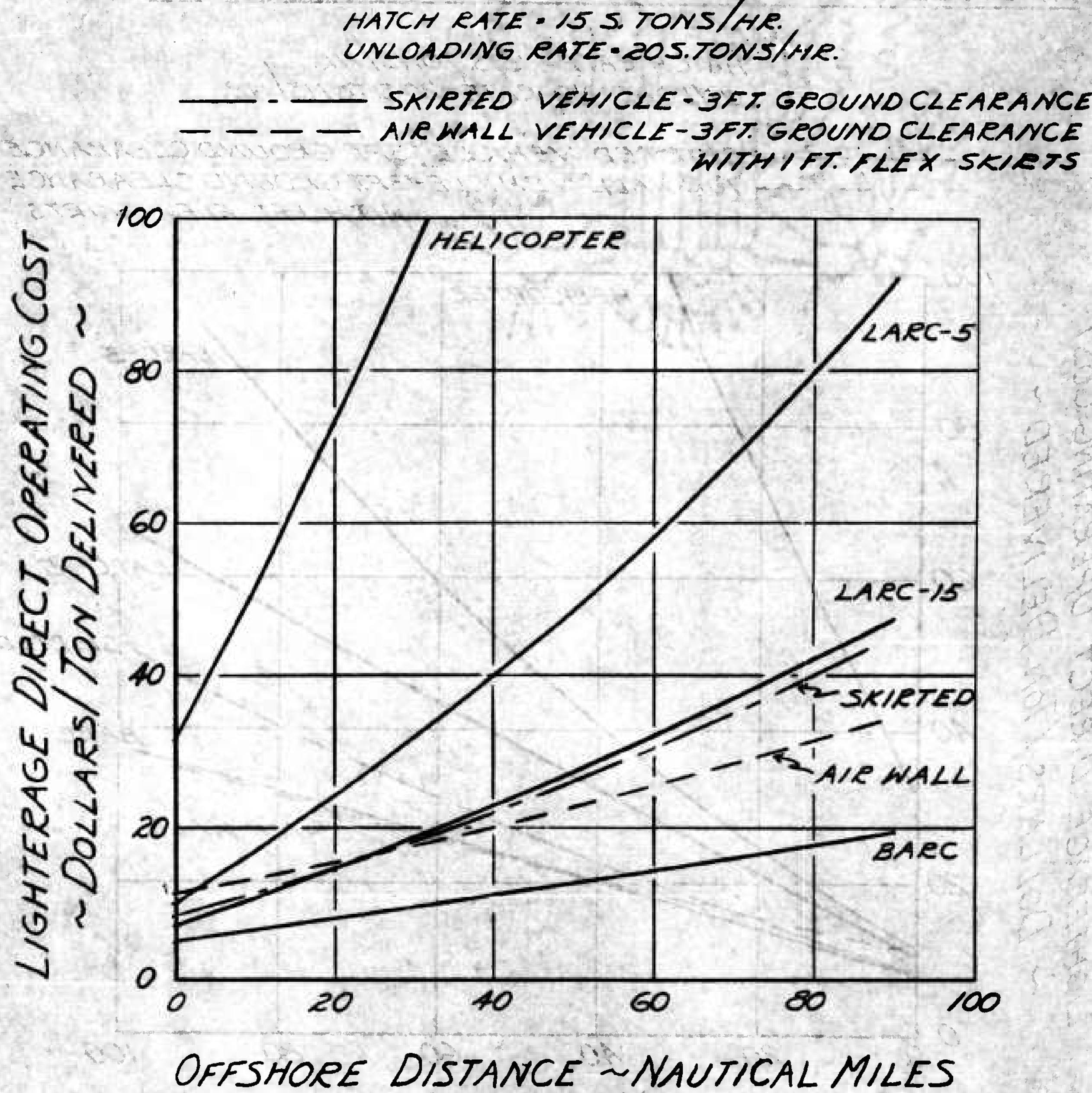


Figure VI-8

(U) LIGHTERAGE DIRECT OPERATING COST
INLAND DISTANCE = 10 N. MILES, PIONEER ROAD
WHEELED AMPHIBIAN VEHICLES SPACE LIMITED

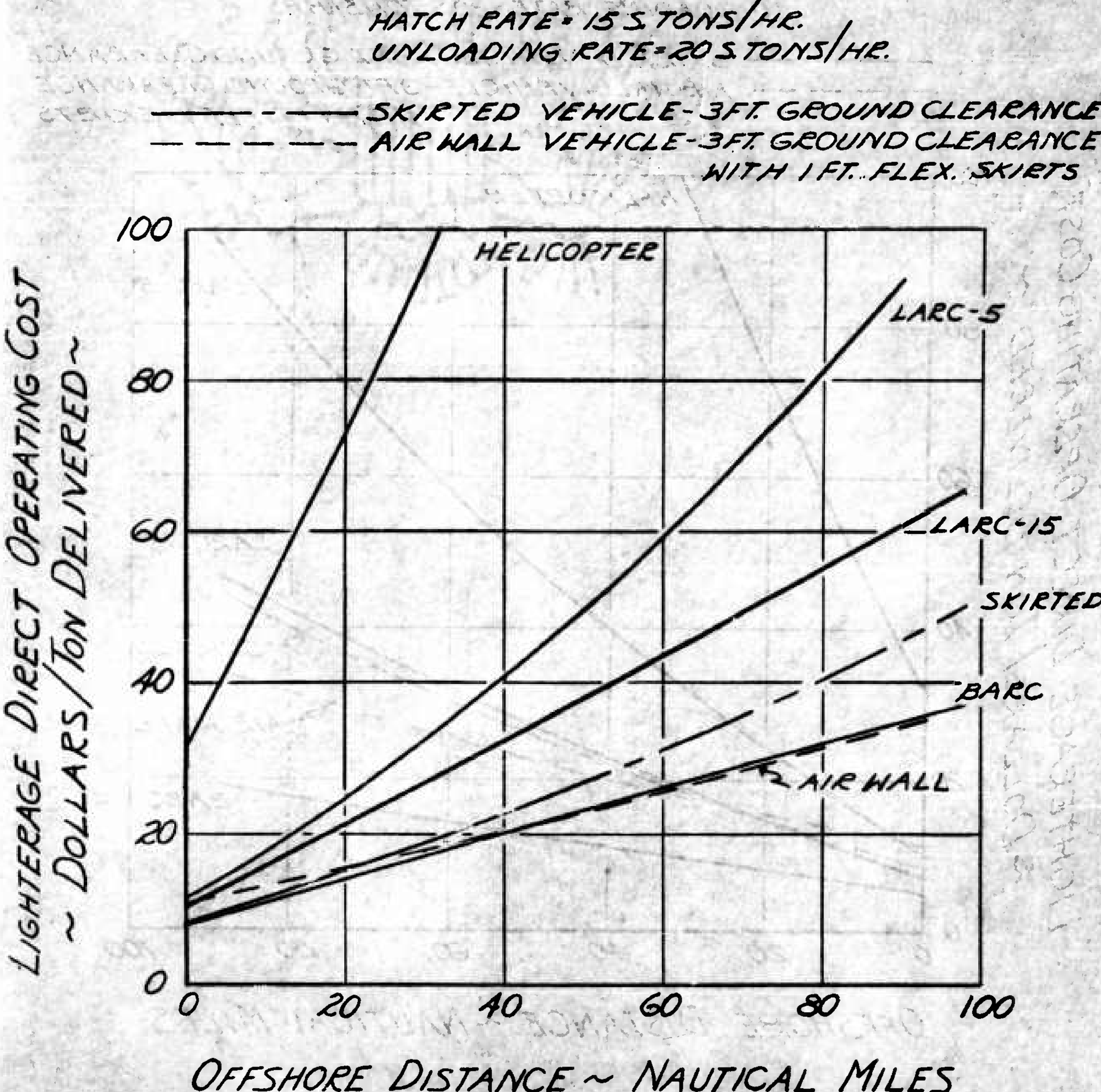


Figure VI-9

Figures VI-5 through VI-9 show the cost of the wheeled amphibians when their payloads are realistically limited to tonnages permitted by their cargo compartment space limitations (See Table VI-1). As discussed in Section III-B, the limitation on payload is particularly applicable when handling resupply military cargo. The BARC is penalized heavily by space limitations, but it may be noted that it is the only lighter being consiered here that can carry a 60 ton item of equipment. It is shown in Section V, however, that the selected air cushion vehicles can carry considerably heavier than their rated payloads when conditions allow the operating height to be reduced.

An example of the increased economies of air cushion vehicle lighterage provided by a 50 percent payload increase is shown on Figures VI-4 and VI-9. The partial skirted air wall vehicle operated at 2.2 foot ground clearance is used for the example; however the same effects are obtainable with the fully skirted vehicle. (Data for the fully skirted vehicle is not presented to avoid further clutter of the Figures.) It should be noted that a 50 percent payload increase causes a very modest reduction in the 3.0 foot design operating height (approximately three-fourth of a foot). Such reductions are probably possible 50 percent of the time, as can be noted on Figure III-14.

The cost of the helicopter exceeds that of the other lighters considered by a factor of two or more. This cost when compared to other lighterage precludes its use as normal lighterage in LOTS operations. Current military and commercial usage illustrates, however, this is considered to be an acceptable cost penalty for the speed and versatility offered by the helicopter in special mission roles.

By comparison the air cushion vehicle provides a significant proportion of the helicopter's speed and versatility and, as shown by the cited Figures, at costs comparable to those of the wheeled amphibians.

2.(U) FUEL CONSUMPTION

Lighterage fuel consumption is shown on Figure VI-10. This fuel consumption was costed at a nominal rate as an integral part of the direct operating cost, but in a particular tactical situation, the POL logistics problem may be critical. The

(U) LIGHTERAGE FUEL CONSUMPTION
INLAND DISTANCE = 5 N.MI., CROSS COUNTRY

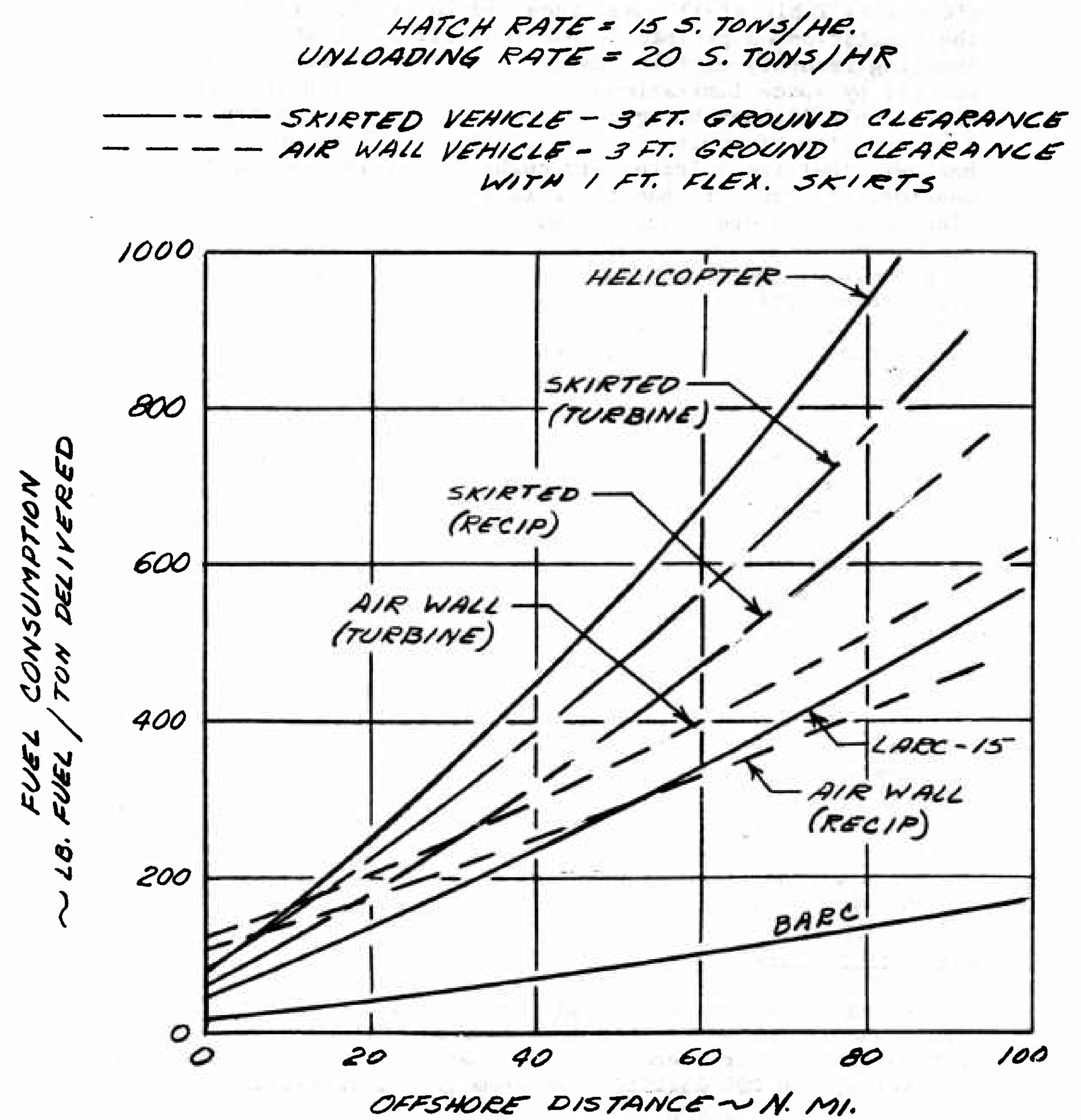


Figure VI-10

magnitude of this problem is indicated in Figure VI-10 in terms of pounds of fuel per ton of cargo delivered. The BARC is immediately seen to be most productive per pound of fuel, and this fact may be attributed to its large payload. It is of interest to note that a large, slow-moving barge is excellent in this respect simply because of the extremely high effective L/D that can be achieved. The selected air-cushion vehicles are competitive with all but the very large conventional lighters.

Reciprocating engine powered versions of the air cushion vehicles are also shown on Figure VI-10 for comparison. A substantial fuel saving can be realized by their use. It was shown in Section V, however, that in terms of total direct operating cost and vehicle size the turbine power plant is more economical.

3 (U) MANPOWER REQUIREMENTS

The TO & E personnel per ton of cargo delivered is shown in Figure VI-11. Because of their speed, the air cushion vehicles are relatively insensitive to range and for longer mission radii are the most economical type in terms of manpower. For short missions the air cushion vehicles are competitive with all other lighterage types.

4 (U) PROCUREMENT COST

Figure VI-12 shows the initial investment required to procure enough lighterage to institute an operation of a given magnitude. For short distances the procurement cost of the air cushion vehicle is estimated to be higher than that of the wheeled amphibians but significantly less than that of helicopters. At longer distances the air cushion vehicle's speed pays off both in versatility and transport economy.

The conclusions to be drawn from the procurement cost data are much the same as those that may be drawn from operating cost--the air cushion vehicles are economically competitive with the wheeled amphibious lighters.

5 (U) NUMBER OF LIGHTERS

The number of lighters required to service a single hatch on a continuous basis is shown on Figure VI-13. The actual

(U) LIGHTERAGE MANPOWER REQUIREMENTS
INLAND DISTANCE = 5 N.MI., CROSS COUNTRY

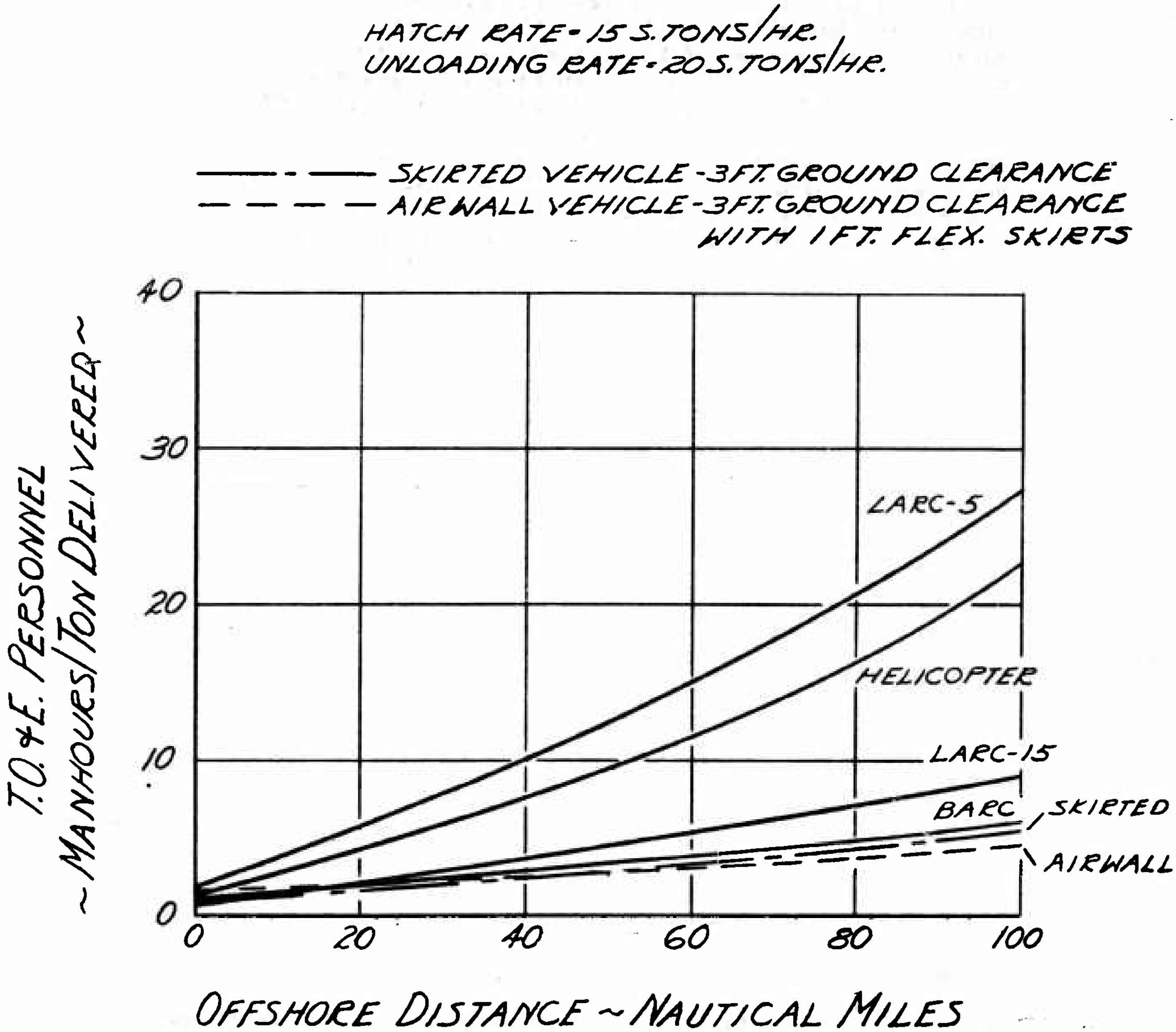


Figure VI-11

(U) LIGHTERAGE PROCUREMENT COST
INLAND DISTANCE = 5 N.MI., CROSS COUNTRY

HATCH RATE = 15 S. TONS/HR.
UNLOADING RATE = 20 S. TONS/HR.

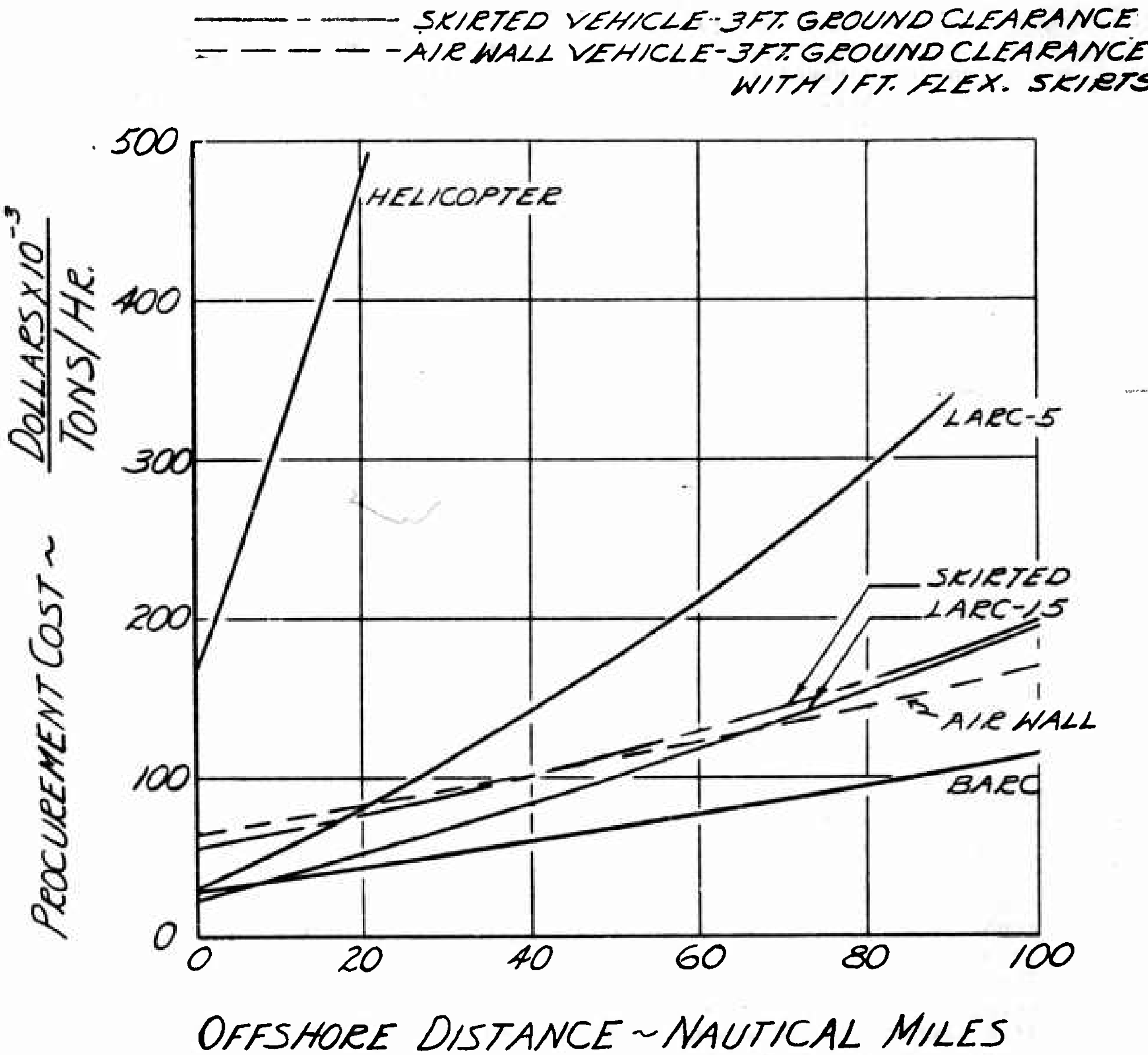


Figure VI-12

number of lighters required in the theater of operation is greater than the number of operating lighters, since the vehicles are not continuously available. Inclusion of the availability factor in the data presented on Figure VI-13 provides a realistic comparison of the total lighters required per ship's hatch.

The low availability of the helicopter (30 percent) in comparison to the other lighters (80 percent availability) causes a significant degradation of its comparative merits. If the helicopter possessed the same availability as credited to the other lighterage, its required numbers would approximate those of the air cushion vehicles.

The significance of availability lies in its key causes--maintenance and operator skill requirements. The importance of minimizing vehicle maintenance and operator skill requirements is implicit in the presented data. Additionally, the number of lighters required reflects in the task of lighterage transhipment to the theater of operation. The lighterage numbers presented on Figure VI-13 are later used to determine transhipment costs.

Additionally, the presented data on number of lighters required for delivery of 300 tons of cargo per day is the inverse of lighterage productivity and, therefore, provides an indication of the relative productivity of the individual lighterage types.

F.(U) RESPONSE TIME-COST CONSIDERATIONS

In an ideal steady state logistics chain, the vehicle speed is not by itself of particular importance (except as it affects the costs) since cargo arrives at the destination at a specified constant rate in all cases. An important aspect of the Army's logistic system is, as previously discussed, its ability to respond to emergency situations. The ability of the lighterage vehicle to provide rapid system response to emergency situations is a significant measure of its military usefulness and effectiveness.

Figure VI-4 shows a comparison of air cushion vehicles, wheeled amphibians, and a helicopter in their ability to respond to supply demands, and the corresponding lighter operating cost. The situation depicted here is a requirement to deliver a priority cargo from a ship 25 nautical miles off-shore to a transfer point five nautical miles inland. If the control center selects an empty lighter near the ship, the time elapsed between the lighter's receipt of the supply order and the completion of unloading at the

(U) NUMBER OF LIGHTERS REQUIRED IN THEATER TO SERVICE ONE HATCH INLAND DISTANCE = 5 N. MI. CROSS COUNTRY

HATCH RATE = 15 S. TONS/HR.
UNLOADING RATE = 20 S. TONS/HR.

——— ———SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE
— — — — —AIR WALL VEHICLE - 3 FT. GROUND CLEARANCE WITH 1 FT. FLEX. SKIRT

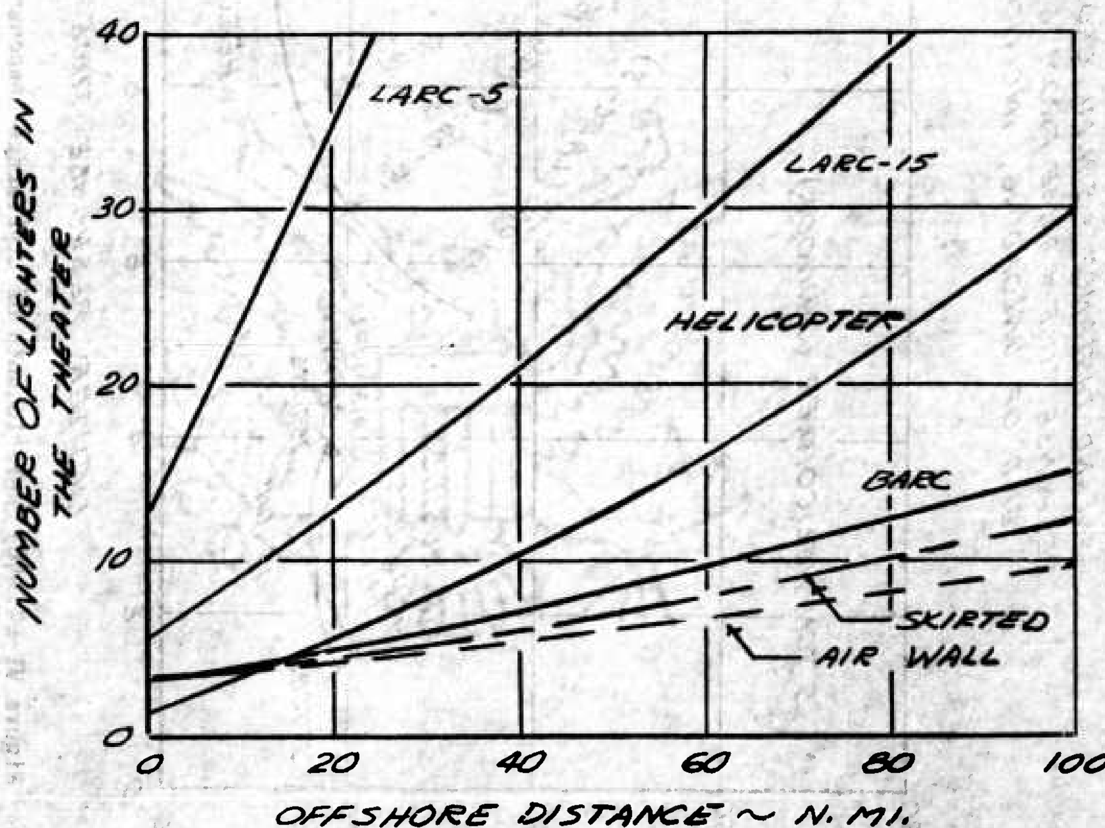


Figure VI-13

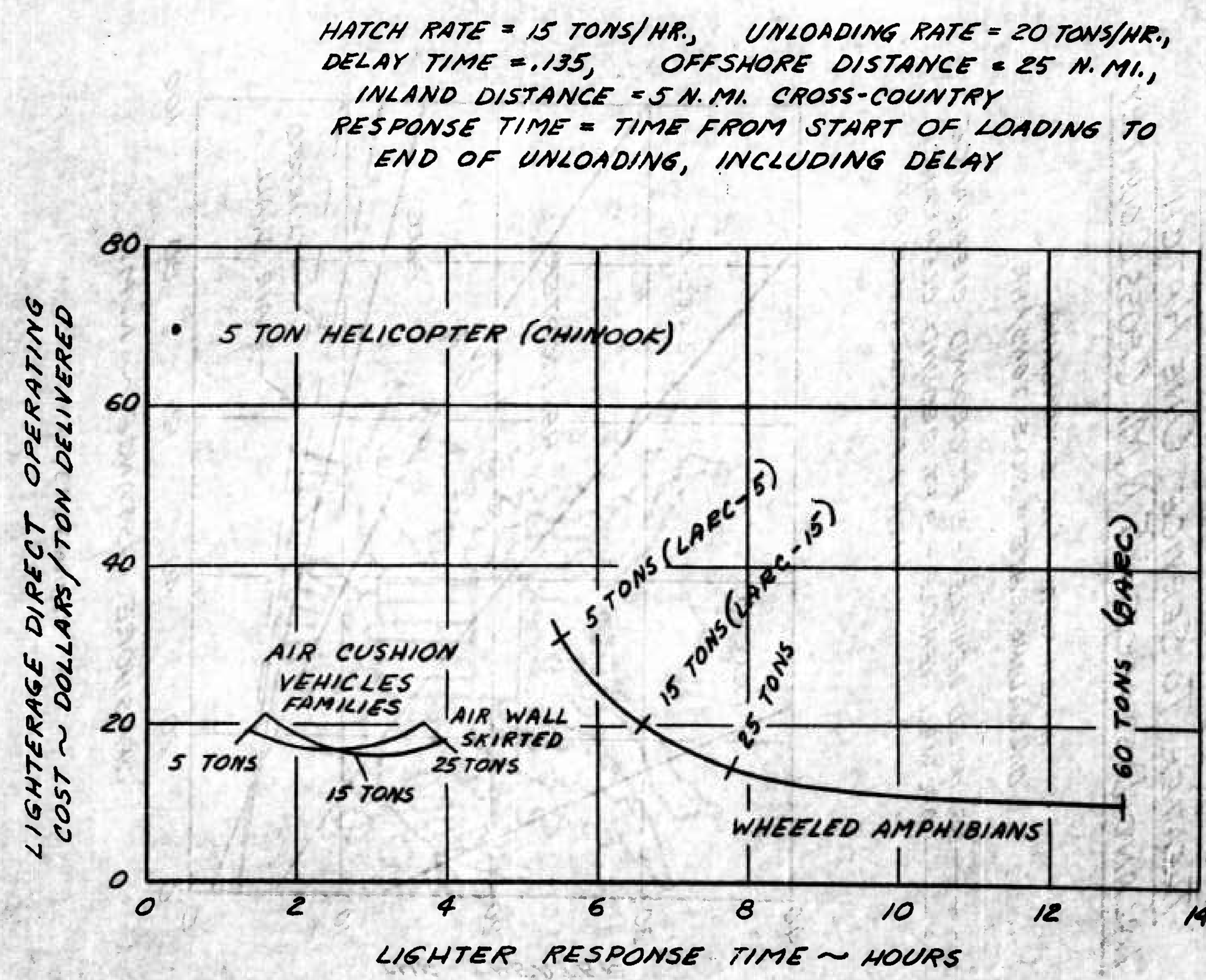


Figure VI-14. (U) Relationship of Lighterage Response Time and Direct Costs.

intransit point is defined as the lighter response time. As shown, the response time of the helicopter is outstanding provided the selected ship has the capability to transfer cargo to the sling, but a significant cost premium is required. If a longer response time is tolerable, the air cushion vehicle family can perform the mission and at costs competitive with the LARC-BARC family.

For example, an air cushion vehicle designed to carry a 5 ton payload has a response time of 1.5 hours, and has an estimated cost of twenty dollars per ton. The 5 ton payload wheeled amphibian (LARC-5) can deliver its payload in 5.5 hours at an estimated cost of thirty dollars per ton. The helicopter can deliver its payload one hour sooner than the air cushion vehicle, but at more than three times the cost.

The figure also shows the increase in response time with increasing payload of the LARC-BARC and ACV families. This effect is caused by the loading and unloading times. Alternatively, if a small specified package of priority cargo were considered, the large lighter could carry that cargo only and eliminate additional loading time. The cost per ton then increases by the ratio of rated payload to payload carried.

The helicopter, within its payload capability, remains the most effective lighter type due to its high-speed capability and its insensitivity to terrain. The air cushion vehicle, however, is competitive on a cost basis with presently existing lighterage and possesses sufficient mobility and speed to give it a significant advantage in flexibility and response capability.

(U) SECTION VII

TOTAL SYSTEM COSTS

The previous section dealt with those costs that could be directly associated with a particular lighter and made no attempt to generate an absolute system cost. A number of costing parameters that can be used to compare lighters result since the costs that were omitted were common to all vehicles, hence did not affect the lighterage direct cost comparison.

In examining the relationship of the lighterage to its environment, however, there are additional costs that must be examined. It is useful to enumerate possible sources of dollar-cost to the logistics system that might be considered. One possible breakdown of these costs is shown below.

(1) Equipment Costs

a. Ships
b. Cargo handling equipment
c. Lighterage
d. Equipment to support and maintain the above functions--CONUS ports, command and control, engineer equipment, engineering support equipment

(2) Manpower Costs

a. Manpower required to operate the above equipment
b. Manpower required to service the above equipment
c. Manpower required for cargo handling (in addition to vehicle operating crew)
d. Manpower required for administrative and support functions

(3) Maintenance Cost (parts and labor)
All equipment associated with the operation

(4) POL Transport and Use
All equipment associated with the operation

The analysis of components of a list such as this can, of course, be pursued in never-ending fashion, depending upon what is defined as "the system", and the degree of detail desired.

The following discussions will consider certain components of cost to the logistics system, where the logistic cycle being considered is from the CONUS port to the inland transfer point. A cost will then be generated which will be termed "system cost", but this terminology is not intended to infer that all of the costs of this logistics cycle have been included. Rather it is the summation of the individual cost components that are considered to be directly affected by alterations in lighterage types and operating methods. Specifically, the components to be discussed in detail are lighterage costs, engineer support costs, cost of transhipment of lighterage, and certain components of the ship costs.

The notable omission of components in the system cost are then the costs of cargo-handling equipment and manpower. Presently available information (Reference 5) indicates that these costs are independent of the lighter type and, although this may not be true in all cases, the tools are not available to rationally assume otherwise. Once this assumption is made, the cargo-handling cost becomes a constant increment to the system cost (expressed as cost per ton delivered), and its inclusion serves no useful purpose in the lighterage comparison.

On a similar basis the costs of command and control and administrative functions are omitted from the system cost. Although these costs may not actually be independent of the lighterage type, the means for their quantification are not available at this time.

Certain components of the system cost are a function of the length of time that the particular LOTS operation continues. These essentially are fixed costs to the operation regardless of its time span and are properly amortized over the total operation time; or, more properly, over the total number of tons of cargo delivered. For the present purposes this period of operation shall be assumed variable between 30 and 360 days to conform to the mission concept discussed in Section II and again in Section VI.

A. SHIP COST

Examination of shipping costs in the logistics cycle reveals that the number of ships in transit at sea and, therefore, their in-transit costs are independent of the LOTS operation. However, the length of time a ship is held at the transfer point is inversely proportional to its cargo unloading (hatch) rate. The ship's port cost will be included in the system cost since hatch rate effects on LOTS operations are of interest. The at-sea cost of shipping is independent of the lighterage as previously indicated and is, therefore, omitted.

Reference 6 shows the cost of a typical cargo ship (C 3) to be $3,840/day fixed cost, plus $100/day for fuel while in port. The mission now being studied concerns itself with only one ship's hatch, and the other hatches are assumed to be similarly employed. The daily cost incurred by our mission due to the ship is then

$$\$\frac{3940}{5} = \$788/\text{day}$$

where the typical (C 3) ship has five hatches. However, since variations in hatch rate are assumed to be caused by variations in cargo packaging and type, rather than cargo handling techniques, a similar variation is, therefore, assumed to occur in the loading rate at CONUS. That is, the assumption is made that any increase in hatch rate is accomplished without additional unit cargo handling costs, and that the charge occurs at the CONUS port as well as at the unloading site. Therefore, to show the effect of hatch rate upon the logistics cycle, including ship cost at both ends of the cycle, a value of twice the above figure, or $1,576 per day per hatch is used. Both the lighterage and CONUS port are assumed to operate 20 hours per day. The ship port cost becomes

$$\text{ship port cost} = \frac{1576}{20 \times (\text{hatch rate})} \text{ dollars/ton.}$$

The ship port cost may be combined with the lighterage direct operating cost from Section VI. The resulting cost is shown on Figure VII-1 as a function of hatch rate with a correspondingly varying unloading rate. Since all costs that are affected by hatch rate are now included, this figure illustrates the total effect of hatch rate resulting from the stated assumptions.

EFFECT OF HATCH RATE ON SHIP PORT + LIGHTERAGE DIRECT OPERATING COST

OFFSHORE DISTANCE = 25 N. MI.
INLAND DISTANCE = 5 N. MI. CROSS COUNTRY
——— - ——— SKIRTED VEHICLE, 3 FT. GROUND CLEARANCE
- - - - - - - AIR WALL VEHICLE, 3 FT. GROUND CLEARANCE WITH 1 FT. FLEXIBLE FLAPS

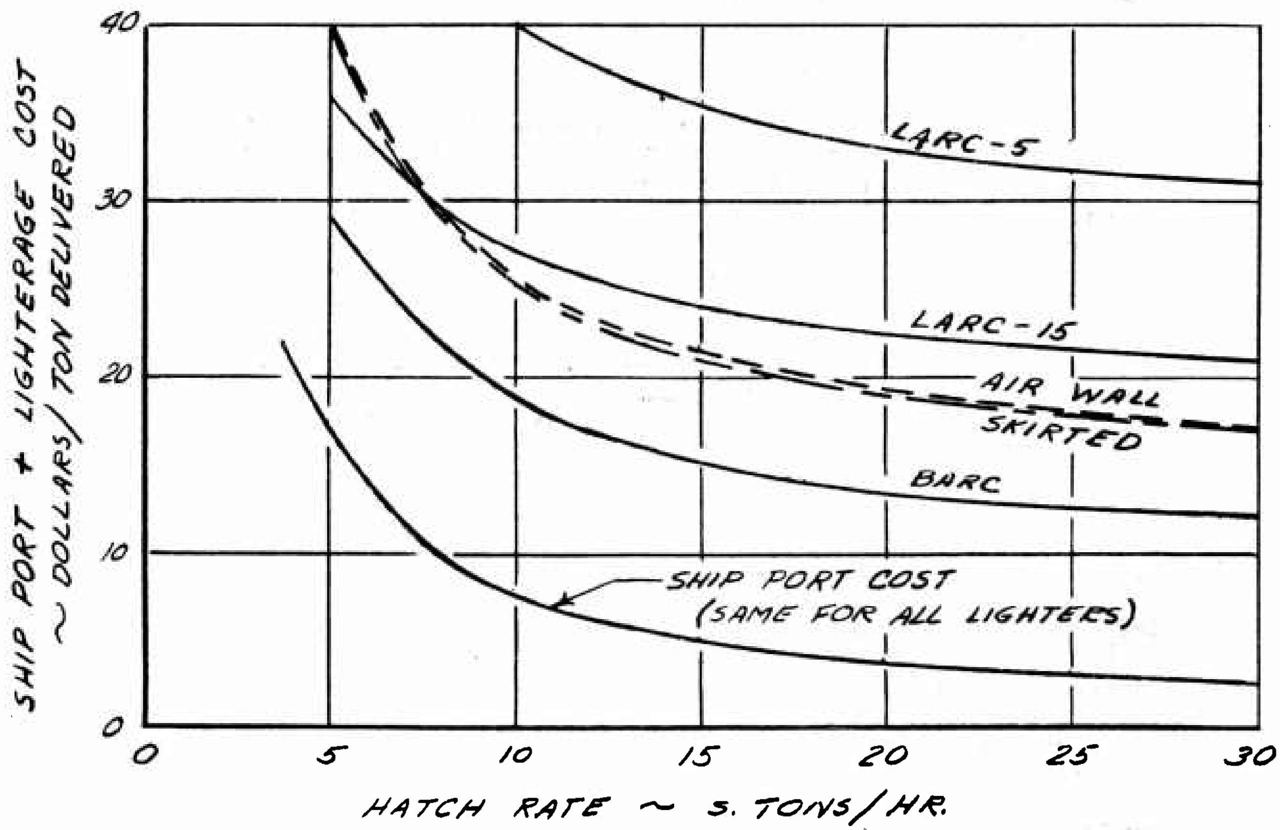


Figure VII-1

In addition to the effect of ship port cost, the lighterage cost increases with decreasing hatch rate because of the longer time spent at shipside. The incremental variation of ship port, plus lighterage cost with hatch rate, is independent of mission radius; thus, the variation shown in Figure VII-1 is applicable to the considered mission radii with a proper adjustment of cost level.

It may be seen from this rather rudimentary analysis that increasing the hatch rate from 7.5 tons per hour (approximate present planning factor) to 15 tons per hour can result in a significant cost saving. Increasing the hatch rate further results in still lower costs, but the savings diminish asymptotically.

It is possible, however, that factors more important than the cost variation shown here affect the desirability of increasing hatch rates. As the hatch rate decreases the required number of both ships and lighters increases because of increased idle times for each. The significance of this factor cannot be quantified in a generalized military environment, but may be of great importance in a particular situation.

For example, current planning factor hatch rates of 7.2 short tons per hour require an average of two ships to be continuously discharging cargo to provide daily resupply of a Division Slice (1,440 short tons of dry cargo per day). Increasing the hatch rate to 15 short tons per hour reduces the number of ships discharging to one; and, due to assumed similar reductions at CONUS, reduces the number of ships per Division Slice in the logistics chain from 10 to 8. In addition, low hatch rates correspond to a lower over-all mobility, increased exposure times and greater vulnerability.

B. INFLUENCE OF ROADWAY COSTS ON TOTAL SYSTEM COSTS

1. DEVELOPMENT OF ROADWAY COSTS

The direct operating costs of the amphibious vehicles, the helicopter and the ACVs have been estimated and compared. An additional significant factor in the over-all cost picture is the roadway cost. Using the construction effort estimates given in Section III, the following cost estimates for roadway construction and ACV clearway construction were developed.

The "net effective man hours" given in Tables III -6 and III - 7 are defined as the actual man-hours of construction effort required. An infantry Division Engineer Battalion has 785 men assigned. It is estimated from FM-101-10 (Reference 1) that such a Battalion represents 130,000 effective man-hours of construction effort per month. If a man-day cost of $14.30 is applied, each construction hour of effort costs

$$\frac{785 \times 30 \times 14.3}{130,000} = \$2.60$$

The following estimates of quantity of materials and man-hours required for road construction were obtained from FM-101-10. The material costs were based on current commercial prices. The figures do not include the man-hours required to clear, grub, strip and rough grade. These estimates were presented in Section III, Table III- 6 .

a. Culvert piping required on the average for one nautical mile of road

One lane	4.86 tons	@ $ .20/lb	= $1950
Two lanes	9.4 tons		= $3770
One lane	1450 man hours	@ $ 2.60/hr	= $3780
Two lanes	2260 man hours		= $5875

b. Steel bridging material required on the average for one nautical mile of road

One lane	49.5 tons	@ $ .25/lb	= $24,800
Two lanes	102.5 tons		= $51,250
One lane	945 man hours	@ $ 2.60/hr	= $ 2,455
Two lanes	1857 man hours		= $ 4.825

c. Gravel for 6" layer for one nautical mile of road

One lane	2030 tons	@ $2.50/ton	= $ 5,070
Two lanes	3720 tons		= $ 9,300

d. Asphalt for 3" layer required for one nautical mile of road

One lane	1030 tons	@ $ 4.00/ton	= $4,060
Two lanes	1860 tons		= $7,450

From the preceding information it is possible to estimate the cost in dollars for the construction of one nautical mile of various types of roads in different terrains. This has been done and is tabulated in Table VII-1 for pioneer roads, dirt roads, gravel roads and asphalt roads.

It is quite apparent that bridge and culvert construction and asphalt surfacing are the most costly portions of the construction effort, both in material cost and man-hours. No estimates of the cost of temporary bridges are included in cost estimates for the pioneer combat road. Such bridges are tactically transportable and reuseable. The man-hours required for emplacement are variable according to the type selected. However, the erection time of floating bridges, and fixed bridges constructed from floating bridge components, varies from 60 to 200 feet of bridge per hour by a squad size erection crew. This represents an insignificant portion of the pioneer combat road construction effort.

In estimating the engineer effort and cost of preparing a clearway for an ACV, the clearing, grubbing, stripping and rough grading man-hour estimates in Table III-6 for pioneer roads have been used as a basis. Bridges are not considered to be required by or adaptable to the ACV. Most existing or combat constructed bridges would be unsuitable for ACVs due to width restrictions, or because they are treadway type construction (unable to provide a ground plane for the air cushion). To allow the ACV to cross streams and cuts may require the bulldozing of entries to and exits from such terrain interruptions. This may add some additional effort to the pioneer road estimates. On the other hand, there will be many stretches of terrain or some routes where no clearing or grading will be required for an ACV. Such types of land as freshly plowed fields, vegetated fields with low foliage plants, flat grasslands (even low rolling grasslands or wastelands) and wetted lowlands can serve as ACV routes with absolutely no preparation at all. Areas of cultivation may require only the flattening of fences, hedgerows or walls. Therefore, it is felt that the use of the estimates given for the pioneer combat road are conservative when applied to an ACV route.

From FM-101-10 it is estimated that 17.5 man-hours per day per nautical mile of road is required for maintenance. This is apparently based on hard surfaced roads. Unsurfaced roads carrying wheeled traffic would most certainly require more maintenance due to wash-out and wheel rutting. An ACV route should require considerably less, if any at all.

Based on the foregoing data and considerations, Table VII-1 was assembled to indicate the man-hour effort and total costs required to construct various types of roads in three different types of terrain.

2. OVERLAND OPERATION COSTS

From the foregoing road construction and maintenance costs the following comparison of the combined direct operating cost and road costs have been generated for the vehicles of interest. From the data in Table VII-1 the costs to construct combat (Pioneer) type roads and the cost to construct hard surface asphalt roads are plotted on Figure VII-2 as a function of roadway width. It has been assumed, based on the limited data available, that the roadway costs will be directly proportional to their width.

The width of each lane of roadway required for the wheeled vehicles was assumed to be six feet wider than the vehicle and the resulting dimensions were used in determining the road construction costs. The same criteria was used to cost the clearways for the ACVs. It is recognized that the ACVs will most probably require somewhat wider lanes than this to allow for crab angle and drift resulting from wind gusts. However, the ACV clearways will not require the grading and earth compacting required by wheeled vehicles. The construction effort normally required by wheeled vehicles for stump and root removal and for surface smoothing and compacting is, therefore, allocated for providing a wider clearway for the ACV route at no additional cost. Therefore, the same width criteria are used for the ACV clearway for determining costs as for the wheeled vehicle roads.

No costs for bridging and culverting are included in the estimates for pioneer roads for the reasons previously stated.

TABLE VII-1

ESTIMATE IN DOLLARS AND MAN-HOURS
TO CONSTRUCT ONE NAUTICAL MILE OF ROADWAY

TERRAIN		PIONEER COMBAT ROAD		ONE LANE ROAD			TWO LANE ROAD		
		14 Ft.	22 Ft.	DIRT	GRAVEL	ASPHALT	DIRT	GRAVEL	ASPHALT
FLAT	Man Hours	1730	2300	7,000	7,900	18,500	10,400	11,900	28,000
PRAIRIE	Dollars	4500	6000	45,000	52,200	83,800	82,000	95,100	144,400
ROLLING	Man Hours	2300	2900	8,600	9,500	20,200	12,300	13,100	29,300
	Dollars	6000	7500	49,000	56,500	88,300	85,000	98,600	147,600
HILLY	Man Hours	2900	3500	10,700	11,600	22,200	13,900	15,600	31,800
FORESTED	Dollars	7500	9000	54,400	62,100	93,500	91,000	104,800	154,000

NOTES:

(1) Pioneer Combat Road includes clearing, grubbing, striping, and rough grading - no bridges or culverts included.

(2) One lane road is 12 feet wide with 4 feet shoulders. Estimates include clearing, grubbing, striping and fine grading. Bridging and culverts are included.

(3) Two lane road is 22 feet wide with 4 feet shoulders.

(4) Included in above cost estimates are man-hour costs and material costs.

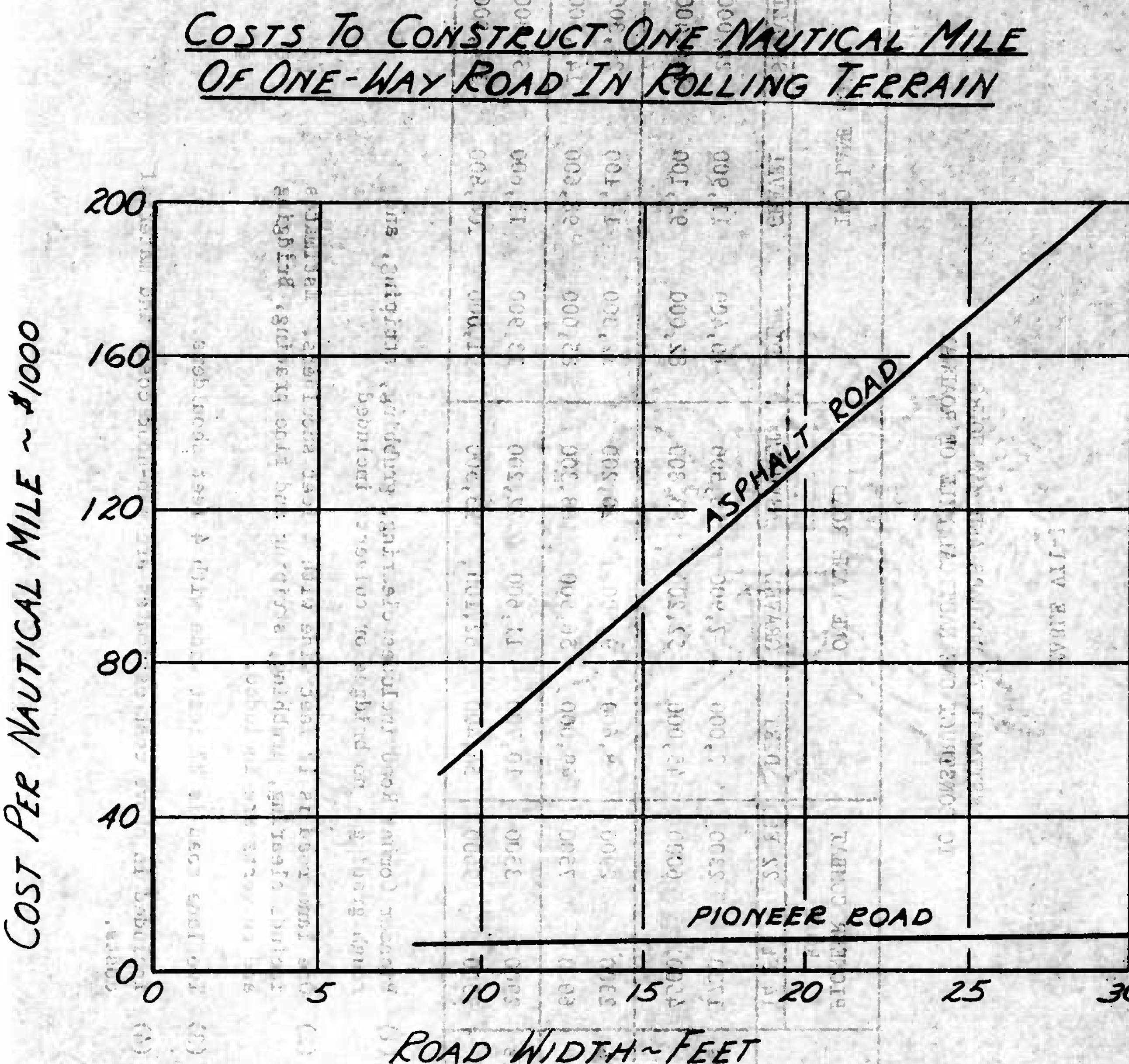

COSTS TO CONSTRUCT ONE NAUTICAL MILE
OF ONE-WAY ROAD IN ROLLING TERRAIN
COST PER NAUTICAL MILE ~ $1000
200
160
120
80
40
0
ASPHALT ROAD
PIONEER ROAD
0
5
10
15
20
25
30
ROAD WIDTH ~ FEET

Figure VII-2

Roadway maintenance is estimated at 17.5 man-hours per day per mile for all roads and clearways, regardless of width or type. It is believed that this assumption favors the wheeled vehicles. As previously mentioned, roads used by wheeled vehicles are subject to rutting and washout of surface dirt and to break-throughs if hard surfaced. The only maintenance requirement that can be foreseen for ACV clearways is the periodic cutting back of accrued vegetation growth or the spraying of "weed killers." Additionally, clearing of rubble caused by military action is seen to represent less of a problem for the ACV clearway.

Six vehicles have been selected for comparison. They are listed in Table VII-2 with the assumed average speed of operation on each roadway over which their operation is contemplated. The payload of each vehicle is also given. The 2½ ton truck has been given a higher (4 ton) payload when operated on hard surfaced roads. This is not done for the ACVs or amphibians because it is assumed that these vehicles are operating in the LOTS mission and their payload will be determined by the water operation. Hard surface road operation of ACVs is not considered since a dirt clearway on which obstructions and uneveness of the surface are less than the normal operating height of the ACV provides just as good a thoroughfare for an ACV as a hard surfaced road provides a wheeled vehicle.

Analysis of the direct operating costs of the 2½ ton truck are given in Table VII-3 and Table VII-4. Consistent with previous assumptions, an operational life of 10,000 hours was selected for wheeled vehicles when operated on hard-surfaced roads. When such vehicles are used on dirt (Pioneer) roads, it was assumed that the operational life would be reduced to two-thirds. When used for off-road operation, the life was assumed to be one-third of the hard surfaced road life.

In Reference 24 (ACV Feasibility Study) a maintenance factor of 15% of initial cost per year, based on a yearly utilization of 2,000 hours, was developed for the 2½ ton truck. The cost analysis for the amphibians in this report assumed a yearly utilization of 4,750 hours. To make the truck maintenance factor consistent with the assumptions and estimates for wheeled amphibians presented

TABLE VII-2

VEHICLE PERFORMANCE

VEHICLE TYPE	X-C SPEED (Knots)	PIONEER ROAD SPEED (Knots)	HARD SURFACE ROAD SPEED (Knots)	MAXIMUM SPEED (Knots)	PAYLOAD S.TONS
LARC-5	4	8	17	22	5
LARC-15	4	8	13	17	15
BARC	3	6	9	13	60
2½ TRUCK	5	10	30	30+	2½, 4*
ACV (Partial Skirt)	15	35	-	80+	10
ACV (Full Skirt)	15	35	-	45+	15

* On Hard Surface Road Only

TABLE VII-3

OPERATING COST ESTIMATES FOR 2½ TON TRUCK
COST PER HOUR

USAGE	OPR. LIFE	AMORTIZED INITIAL COST Per Hr.	PERSONNEL COST Per Hr.	MAINT. LEVEL %Per Yr.	MAINT. COST Per Hr.	ATTRITION COST Per Hr.	FUEL COST Pr.Hr.	TOTAL OPR. COST Pr.Hr.
Highway	10,000	.75	2.86	35	.56	.19	.48	4.84
Pioneer Road	6,666	1.13	2.86	70	1.12	.19	.48	5.78
X-C	3,333	2.25	2.86	105	1.69	.19	.48	7.47

Initial Cost	=	$7,500 ($0.66 per pound)
Maintenance	=	Percent of initial cost per year
Attrition	=	5% of initial cost per year
Utilization	=	4750 hours per year
Crew	=	2 men
Crew Cost	=	$1.43 per hour per man

TABLE VII-4

COST PER TON-MILE FOR 2½ TON TRUCK

USAGE	OPERATING COST Per Hr.	PAYLOAD S.Tons	AVERAGE SPEED (Knots)	TIME TOTAL OF 1 MILE EACH WAY Hrs.	COST PER TON-MILE
HIGHWAY	4.84	4.0	30	.067	.081
			20	.10	.121
PIONEER ROAD	5.78	2.5	20	.10	.231
			10	.20	.462
X-C	7.47	2.5	5	.4	1.20

in Section VI, the maintenance of the 2½ ton truck is estimated at 35% of initial cost utilization per year. For pioneer road operation, based on 4,750 hours, the maintenance is doubled and for off-road operation it is tripled.

The direct operating costs for the amphibians and for the ACVs as developed in the previous Section VI have been used here.

Reference 1 (FM-101-10) states that one primary two-way road forward to the battle area per division is normal planning. The movement of 1,440 tons of cargo per day over each road is, therefore, assumed, as this represents the daily dry cargo resupply requirements of a division "slice". Thus, it is assumed that one two-way resupply route per division is normally adequate for wheeled vehicles carrying this quantity of daily tonnage without overloading the road with traffic.

The total cost per ton mile of radius, including road or clearway construction and maintenance, has been computed by the following equation:

$$C_{TOT} = \frac{C_V \times T}{P} + \frac{C_R + C_M X}{1440 X}$$

where

C_{TOT}	is the total cost per ton nautical mile (two-way routes with cargo hauled one way)
C_V	is the direct operating cost of the vehicle per hour of operation
C_R	is the cost of constructing one mile of two-way road or clearway
C_M	is the cost of maintaining one mile of two-way route per day
T	is the round trip travel time (two miles divided by vehicle speed)
X	is the number of days the supply route is used.
1440	= tons/day for a Division Slice
P	= Vehicle Payload in Tons

Figure VII-3 presents the total cost per ton nautical mile of radius for each vehicle operated over each type of route as a function of operation period. This total cost includes all direct vehicle operating costs and the route construction

and maintenance costs as described herein. The primary information which can be derived from Figure VII-3 is the operational time spans at which various route construction becomes economically advantageous, and the relative economy of operation of various vehicles when route costs are included in the cost picture.

The 2½ ton truck has been included to provide a generally known and recognized comparison point. It does not, of course, possess the amphibious capability required for the LOTS mission, but can be used as a reference in evaluating the inland operation of the LOTS vehicles.

Figure VII-3 shows that hard-surfaced roads must be used for a substantial period of time before they begin to pay for themselves. The LARC-5 must be operated for 9 months; the LARC 15, for almost two years; and the truck, for 10 months before operation on hard surface roads becomes less costly per ton mile than pioneer road operation. These time periods would be shortened if daily tonnage in excess of the 1,440 tons assumed here were considered. Pioneer type roads and clearways will pay off in a very short period of operation-on the order of weeks. Pioneer roads for the LARC-5, LARC-15 and the truck apparently become economically advantageous if operations lasting as little as two weeks are contemplated. Operation of the BARC on pioneer roads pays off if operations exceed three weeks. Clearways for the ACV use would begin to pay off within one to one and a half months of operation. If operations are to extend over time periods of less than six weeks, the fully skirted ACV operated cross-country over scouted routes offers the most economical operation, a factor of two better than a 2½ ton truck operated off-road. The BARC is less economical than ACV in cross-country, but appears somewhat more economical than the 2½ ton truck in off-road operations. The use of the BARC in a true cross-country operation is somewhat questionable however, due to its lack of a suspension system and its size. Neither the LARC 5 nor the LARC-15 appears as economical as the truck in off-road operation.

It is concluded that when operations are expected to extend for periods greater than six weeks but less than a year, the ACVs and the BARC operated over clearways and pioneer roads, respectively, offer greater operational economy than the other vehicles. The 2½ ton truck operated over hard-surfaced roads provides the most economical operation if the road can be utilized for periods exceeding one year.

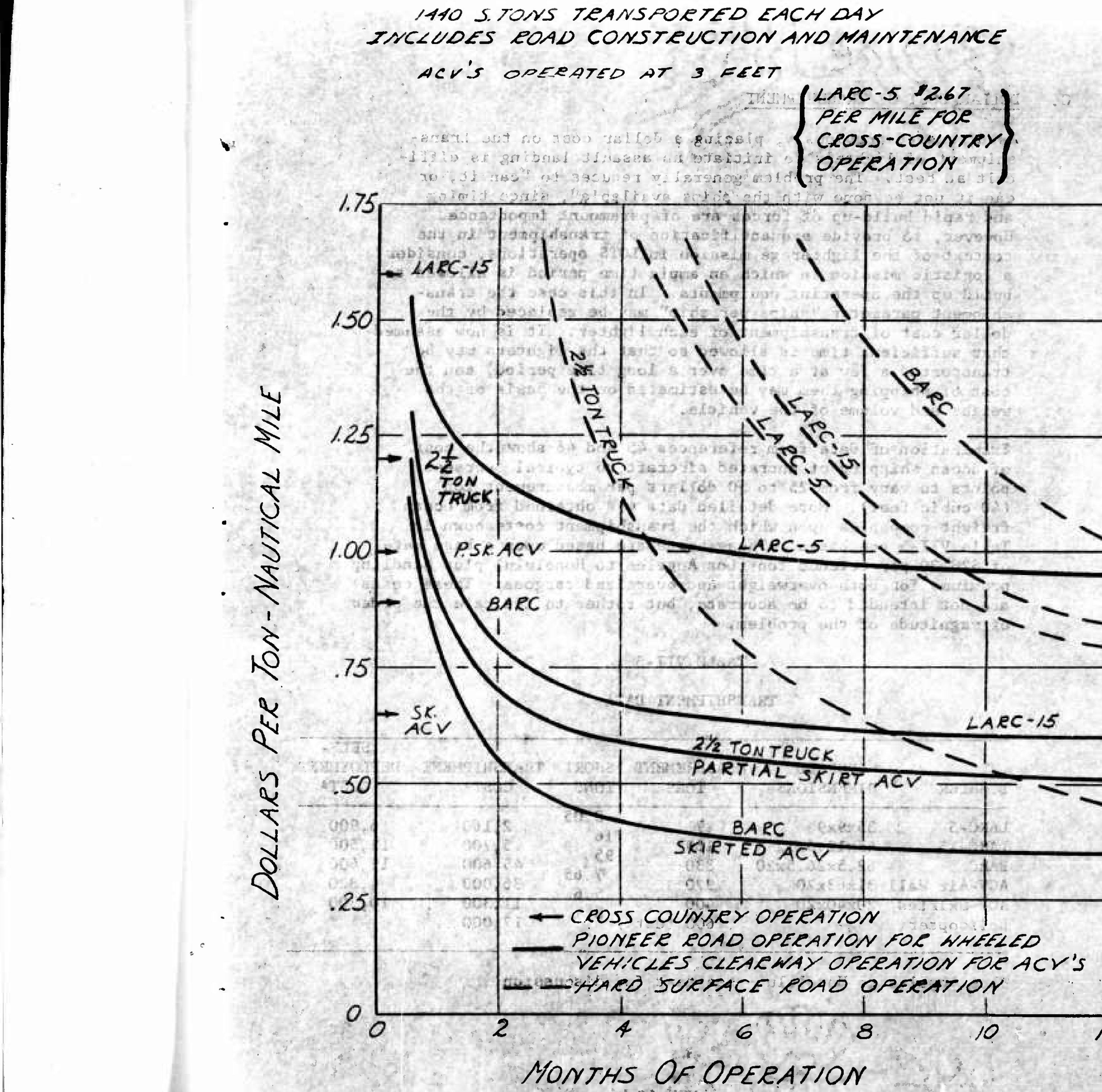


Figure VII-3. Costs to Transport One Short Ton of Cargo 1 N. Mile Over Land and Return Empty.

C. DOLLAR COST OF TRANSHIPMENT

As discussed previously, placing a dollar cost on the transhipment of lighters to initiate an assault landing is difficult at best. The problem generally reduces to "can it, or can it not be done with the ships available", since timing and rapid build-up of forces are of paramount importance. However, to provide a quantification of transhipment in the context of the lighterage mission in LOTS operations, consider a logistic mission in which an ample time period is allowed to build up the operating equipments. In this case the transhipment parameter "ships per ship" may be replaced by the dollar cost of transhipment of each lighter. It is now assumed that sufficient time is allowed so that the lighters may be transported a few at a time over a long time period, and the cost of shipping them may be estimated on the basis of the weight and volume of the vehicle.

Examination of data from references 45 and 46 shows the cost of ocean shipping of uncrated aircraft to typical overseas points to vary from 25 to 50 dollars per measurement ton (40 cubic feet). More detailed data was obtained from ocean freight companies upon which the transhipment costs shown in Table VII-5 are based. These costs are based upon a base rate of $28.30 per revenue ton (Los Angeles to Honolulu) plus handling premiums for both overweight and oversized cargoes. These costs are not intended to be accurate, but rather to indicate the order of magnitude of the problem.

TABLE VII-5

TRANSHIPMENT DATA

LIGHTER	OVERALL DIMENSIONS	MEASUREMENT TONS	SHORT TONS	TRANSHIPMENT COST*	SELF-DEPLOYMENT COST*
LARC-5	35x9x9	71	8.05	2,160	6,900
LARC-15	45x12.5x12	169	16	5,700	12,500
BARC	62.5x26.5x20	830	95	45,600	19,400
ACV-Air Wall	31x63x20	970	7.65	36,000	4,820
ACV-Skirted	20x40x20	400	5.6	11,300	10,300
Helicopter	-	600 (est.)	8.1	17,000	-

*Los Angeles to Honolulu - see text for discussion.

Converting the cost per lighter to cost per ton delivered in the lighterage mission, requires specification of a period of amortization of the transhipment cost. That is, it is assumed that the operation continues for some fixed period of time, and the transhipment operation must then be repeated and the operation repeated at another geographic location. Using the nomenclature of Section VI the cost per ton becomes

$$\frac{N}{20AH} \times \frac{\text{cost of transhipping one lighter}}{\text{period of amortization, days}} = \$/\text{Ton}$$

Due to the costing assumptions employed, the period of amortization must be limited to a maximum of 770 days, since the lighter is then assumed to be worn out and must be replaced. Vehicles lost by attrition must likewise be transhipped, but this cost may be shown to disappear within the accuracy of the present analysis.

The resulting cost to the lighterage mission is shown in Figure VII-4. It may be seen that the transhipment cost is a significant component of the lighterage mission cost for short-duration operations. For operations approaching one year, only the cost associated with the BARC and the air-wall air cushion vehicle remain truly significant.

Moving the lighterage to the theater of operation under its own power may also be considered. The estimated cost for this is shown in Table VII-5 and is estimated by using the vehicle operating speeds and costs shown in Section VI. The costs so derived were arbitrarily doubled to cover the costs of providing fuel tankage, navigation aids, and crew comfort facilities. Practicality of the operation and vehicle maximum ranges are ignored for the moment. On this simplified basis, only the BARC and the air-wall air cushion vehicle appear to have a significant self-deployment advantage from an economic standpoint. Practicality makes dubious self-deployment of the BARC, as discussed in Section III. However, based on the data in Table VII-5, self-deployment of the air-wall air cushion vehicle shows a cost advantage over transhipment by a factor of seven.

Both of the air cushion vehicles considered actually have the range capacity to cross from Los Angeles to Honolulu (2,200 nautical miles) when loaded beyond design payload. However, shorter trips (1500 nautical miles) from advance bases to the LOTS operating area are possible without exceeding the vehicle's design weight. The above costing comparisons are, therefore, valid and are useful on a relative basis for shorter trips or for a series of shorter legs in the self-deployment mode. Further considerations of feasibility of self-deployment of the air cusion vehicles are discussed in Section III.

D. TOTAL SYSTEM COST

The system cost is defined as the sum of direct operating cost, ship port cost, engineer support cost, and transhipment cost. As discussed previously, the engineer support (road) cost and the cost of transhipment of the lighters are fixed costs at the beginning of the operation. These costs are amortized over the time period that the roads are subsequently used and that the lighters remain in use in that geographic area.

The resulting system cost is shown for the air cushion vehicle and the LARC-15 in Figures VII-5 and VII-6. The cost shown is for an offshore distance of 25 nautical miles and an inland distance of 5 nautical miles. While these distances are greater than current planning factors indicated for the LOTS mission they are considered to be possible and desirable in the light of nuclear and medium-short range missile threat in the 1965-1970 time period. The cost is shown as a function of the amortization period, which, in this case, is assumed to be the same for the road as for the transhipment cost. It is most probable as discussed previously, that the same ship unloading and inland transfer sites may be periodically shifted, requiring new roads to be constructed. If the logistics operation continues in the local area, however, the transhipment of lighterage need not be repeated, and the roads then have a shorter amortization period than the transhipment. The amortization period of transhipment must, in no case, exceed the operational life of the lighters.

Figure VII-7 shows a summary of the system costs for all lighters operating over 5 nautical miles of pioneer road and 25 nautical miles offshore. The road and the transhipment operation are assumed to have the same amortization period. Figure VII-8 shown for a 90 day amortization period, is for cross-country operation, and there is, therefore, no road cost.

The cost of the road, however, is much less than the savings in lighter operating cost realized by the road's use. The transhipment cost is slightly less on the pioneer road because fewer lighters are required than for cross-country operation.

The cost for transhipment of both the BARC and the air wall air cushion vehicle is a significant portion of the total system cost if the time of operation is less than 200 days. The high cost of transhipment of the BARC, combined with the availability of shipping and equipment capable of handling the BARC, suggest the use of the pre-deployment technique when possible.

COST OF TRANSHIPMENT OF LIGHTERAGE VEHICLES

OVERLAND DISTANCE = 5 N. MI. CROSS COUNTRY, OFFSHORE DISTANCE = 25 N.MI., HATCH RATE = 15 S. TONS/HR., UNLOADING RATE = 20 S. TONS/HR.

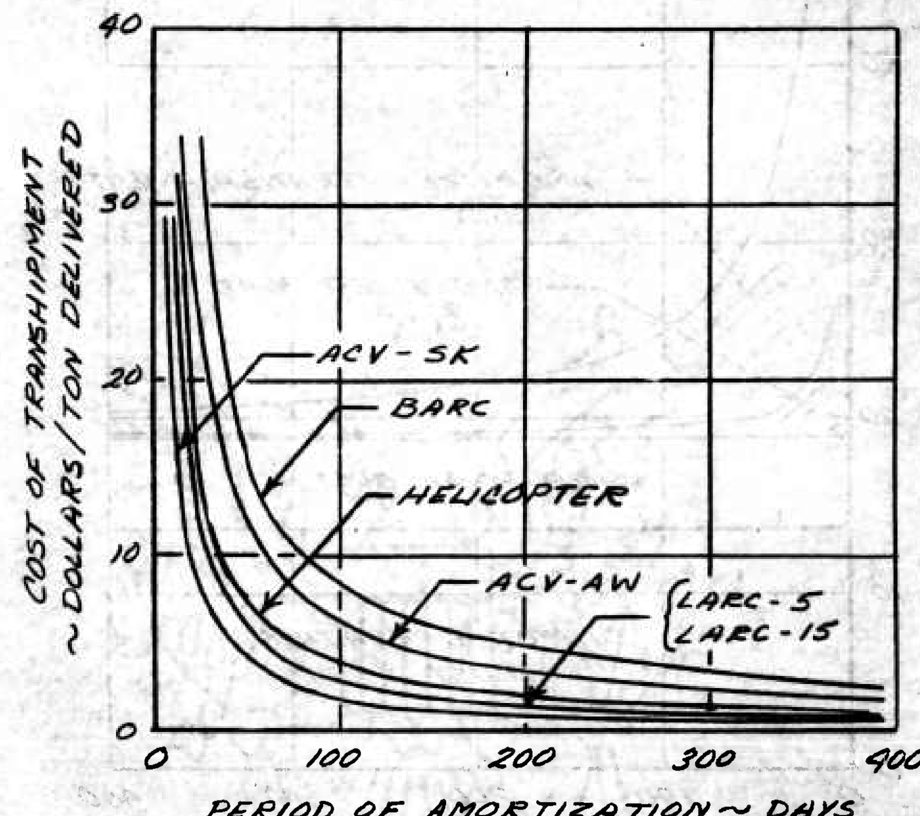
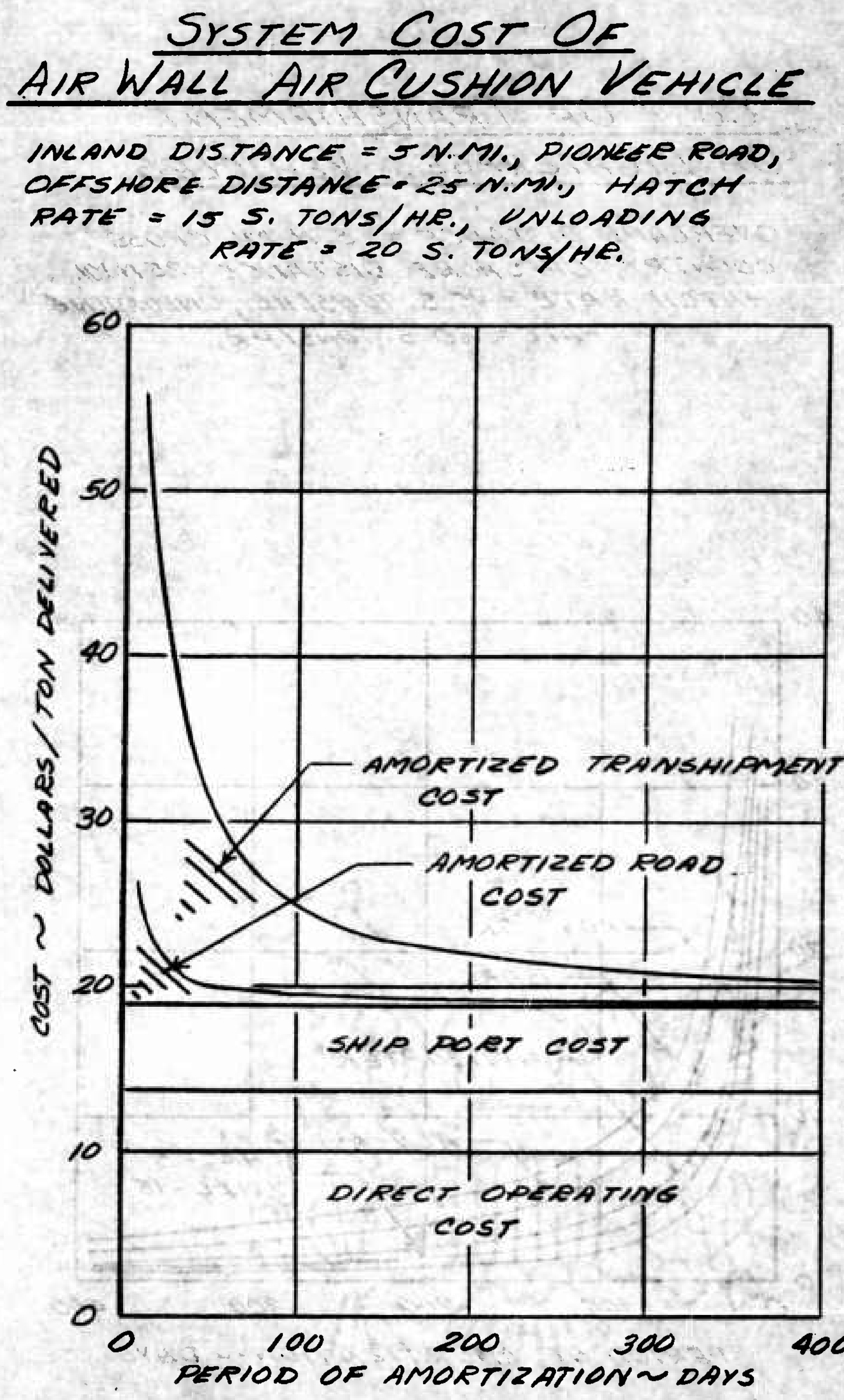


Figure VII-4



SYSTEM COST OF
AIR WALL AIR CUSHION VEHICLE
INLAND DISTANCE = 5 N.MI., PIONEER ROAD,
OFFSHORE DISTANCE = 25 N.MI., HATCH
RATE = 15 S. TONS/HR., UNLOADING
RATE = 20 S. TONS/HR.
COST ~ DOLLARS/TON DELIVERED
60
50
40
30
20
10
0
AMORTIZED TRANSHIPMENT
COST
AMORTIZED ROAD
COST
SHIP PORT COST
DIRECT OPERATING
COST
0
100
200
300
400
PERIOD OF AMORTIZATION ~ DAYS

Figure VII-5

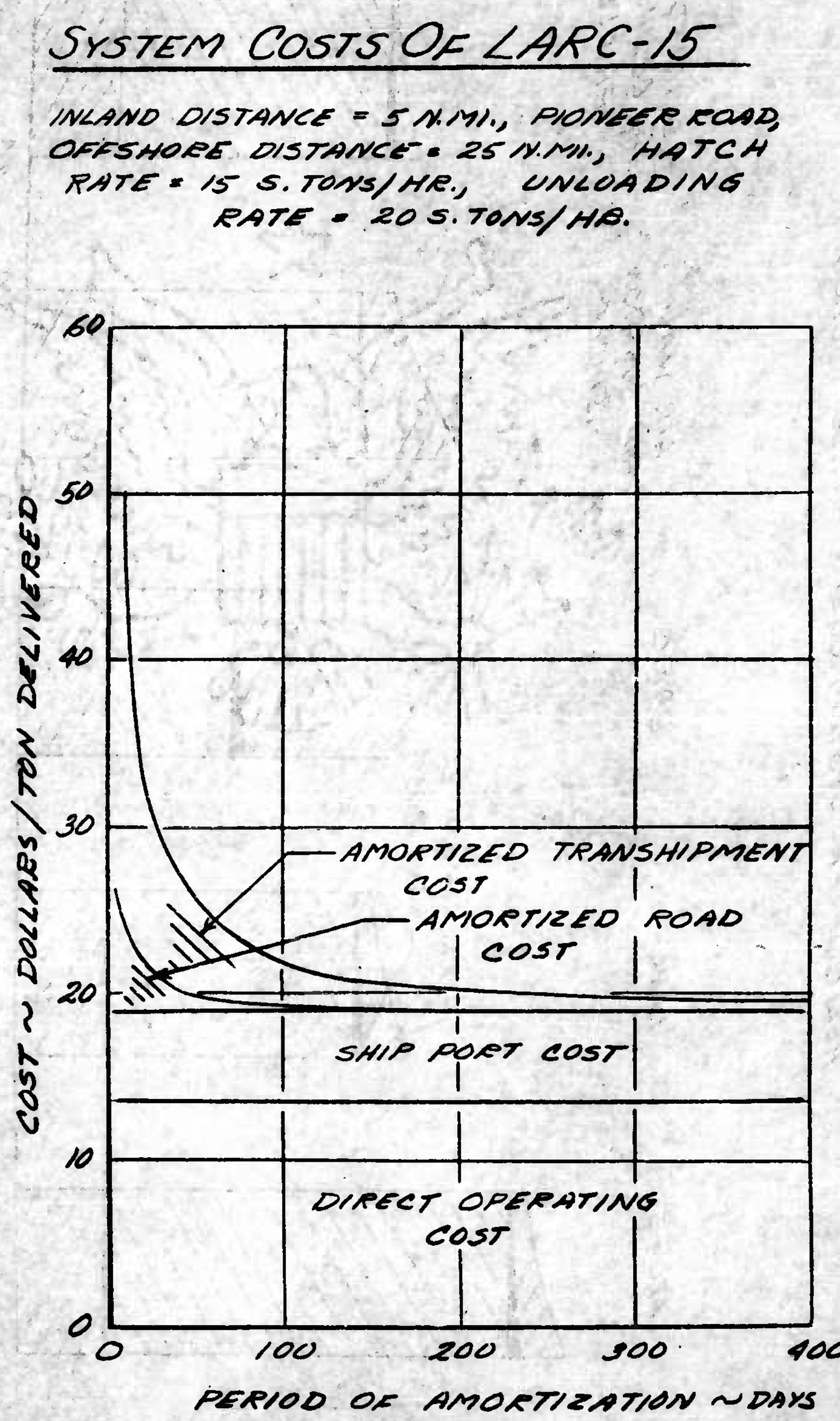

SYSTEM COSTS OF LARC-15
INLAND DISTANCE = 5 N.MI., PIONEER ROAD, OFFSHORE DISTANCE = 25 N.MI., HATCH RATE = 15 S. TONS/HR., UNLOADING RATE = 20 S. TONS/HR.
COST ~ DOLLARS/TON DELIVERED
60
50
40
30
20
10
0
AMORTIZED TRANSHIPMENT COST
AMORTIZED ROAD COST
SHIP PORT COST
DIRECT OPERATING COST
0
100
200
300
400
PERIOD OF AMORTIZATION ~ DAYS

Figure VII-6

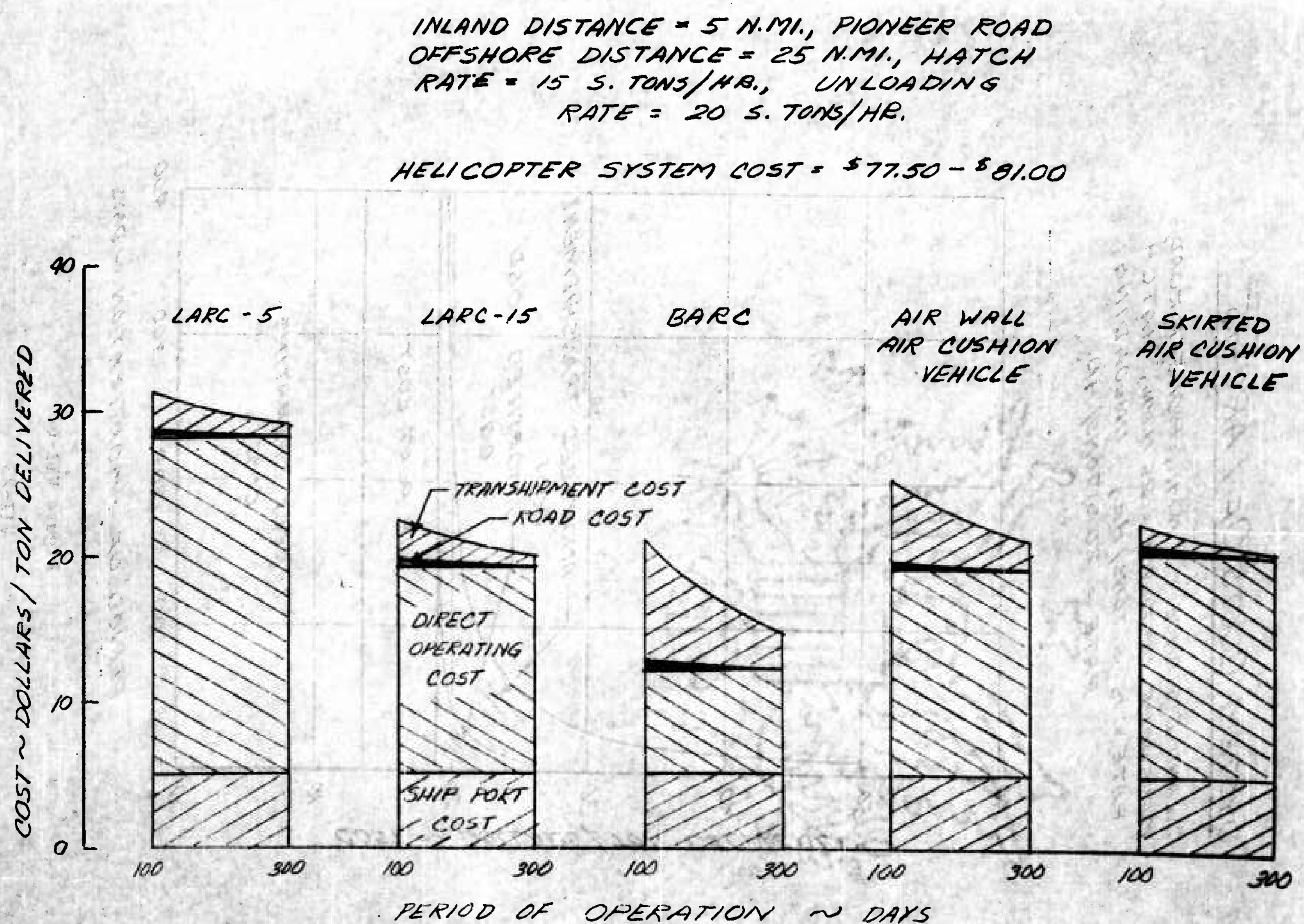


Figure VII-7. Lighterage System Costs.

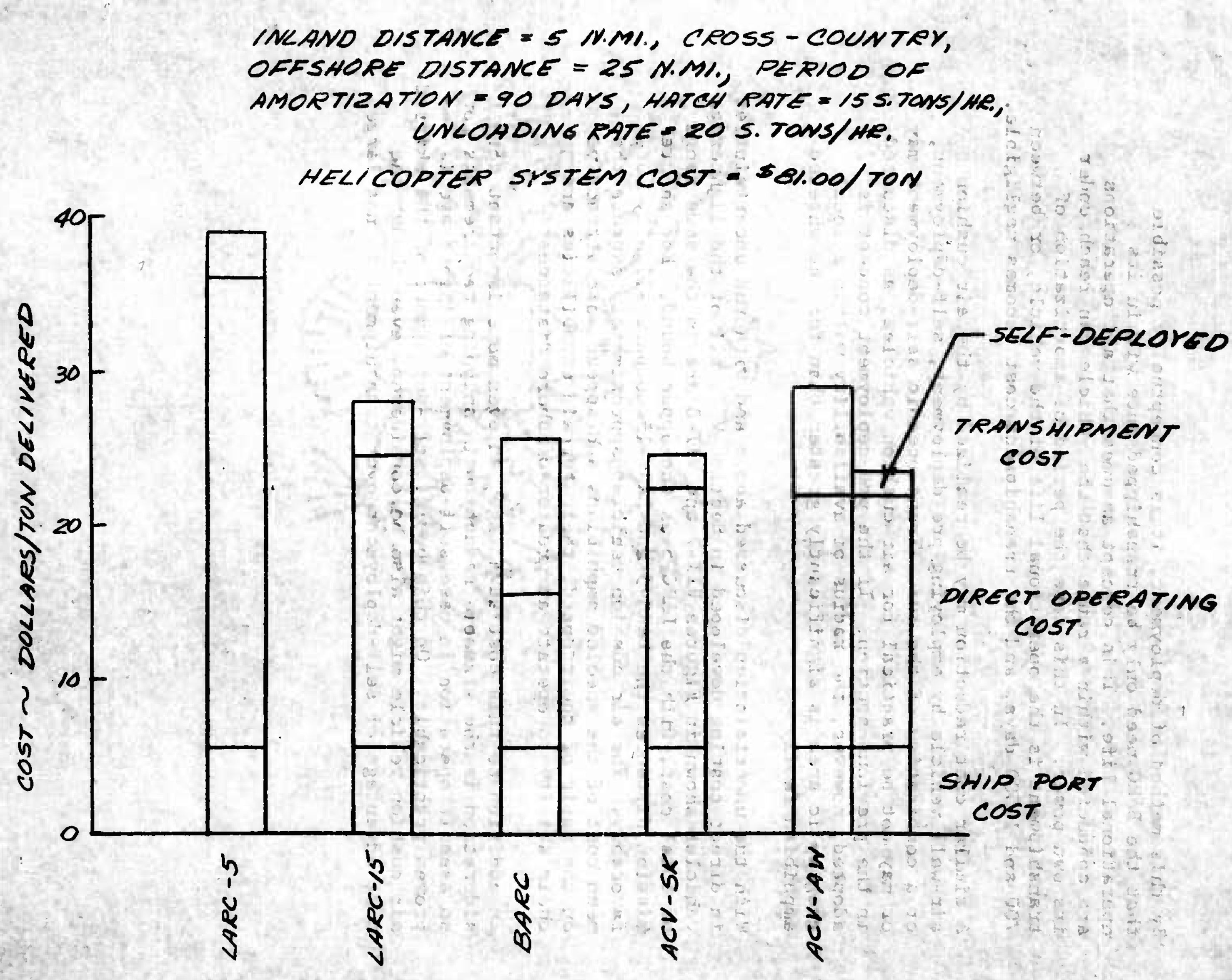


Figure VII-8. System Costs.

By this method of deployment, it is conceptually possible that the BARC need only be transhipped once within its operational life. This concept assumes that all operations are conducted within a range that the vehicle can reach under its own power. In this case the period of amortization of transhipment is the operational life of the vehicle, or between 700 and 1,500 days, and the transhipment cost becomes negligible.

A similar cost reduction may be realized by the air cushion air-wall vehicle by employing pre-deployment, self-deployment, or a combination of the two. Trans-oceanic self-deployment may or may not be practical for air cushion vehicles, as discussed in the previous section. If the pre-deployment concept is adopted, however, the radius of availability within a local geographic area is significantly greater than for the wheeled amphibian family.

With the uncertainties discussed above and with the uncertainties in direct costing developed in Section VII, all of the lighterage vehicles shown in Figures VII-7 and VII-8 are in the same range of total cost, with the LARC-5 as the upper bound. For shorter mission distances the LARC-5 and LARC-15 compare slightly more favorably. The air cushion vehicles approximately express the mean cost of the wheeled amphibians and appear more attractive on the basis of their speed, their terrain capabilities and their ability to operate at greater offshore distances.

In addition to this cost advantage, an even more important consideration is the sizeable reduction in shipping requirements for an assault operation in case self-deployment of lighterage is proven practicable. On this basis, self-deployment of the skirted air cushion vehicle might also be considered, even though the cost advantage of self-deployment over transhipment is not large.

(U) SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

On the basis of this analysis, general engineering knowledge and the limited industry wide experience in the design and operation of ACVs, the following conclusions have been reached as to the use of ACV lighters in LOTS operations.

1. The ACV lighter can be made economically competitive with the present inventory of wheeled amphibious lighters for the environments and distances of currently planned LOTS resupply missions. Additionally, the ACV lighter has potential of reducing the total lighterage inventory and the manpower associated with lighter operations.

2. The ACV lighter offers the capability to economically extend the possible shoreline and inland terrain environments and the mission distances over which LOTS operations can be conducted.

3. The ACV lighter provides the flexibility and more immediate response required to meet the exigencies of a dispersed and rapidly moving military situation.

4. The ACV lighter is operationally compatible with existing equipments which it may replace progressively, as it is introduced into service. It is also operationally compatible with the current and projected inventory of complementary and supporting equipments with which it must be operated in the LOTS application.

5. The ACV lighter can be introduced into the Army inventory without untoward impact upon organizational structure or applicable standing operational procedures.

6. In operations based on currently specified LOTS mission operating distances, the transhipment of equivalent productive capacity of ACV lighterage poses no greater problem than does the transhipment of wheeled amphibians. Should average lighter operating distances greater than those currently planned be imposed, a greater productive capacity in ACV lighterage can be transhipped in an average group of MSTS type shipping. Additionally, self deployment of the ACV appears economically and operationally possible due to its high speed and its ability to clear increasingly higher waves as the mission progresses. However, confirmation of the practicability of ACV self deployment must await operational tests.

7. Cross-country operation of the air cushion lighterage vehicle, as with ground contact vehicles, is dependent upon the terrain and lateral obstruction environment. Environments permitting, cross-country operation of the ACV lighter provides economy of operation which exceeds that of ground contact vehicles with similar payload capacities. Additionally, the ACV lighters, with use of minimal engineer support for provision of clear-ways, attain inland operational economies which exceed those of all but the largest payload wheeled amphibian (BARC) when the later is operated on pioneer roads.

8. The ACV lighter has secondary potential as an amphibious ferry and a bulk fuel lighter.

9. The quantative analysis indicates that the economics and characteristics of ACV lighterage are particularly sensitive to their structural weight. A precise determination of structural loadings resulting from the most unfavorable environments permitting practical lighterage operations is, therefore, necessary for proper structural design.

10. The potential reductions in lighterage cost and vehicle size resulting from the use of flexible skirt elements on either the plenum chamber or peripheral jet vehicle concepts makes the continuing consideration of their use obligatory. The unknowns of skirt element structural design, abrasive resistance and ground and water drag can significantly effect the selection of appropriate vehicle configurations and to a lesser extent the performance criteria to attain minimum

lighterage costs. It is necessary, therefore, to determine skirt element characteristics and drag by experimental tests.

11. Two configurations of ACV lighterage presenting superior but significantly dissimilar technical characteristics are recommended by the results of the study. The dissimilarities are the result of the degree of skirting employed, and serve to emphasize the need for additional detailed skirt and vehicle design refinement. The dissimilarities and military advantages of each of the two configurations follow:

a.

Configuration	partially skirted peripheral jet
Load capacity	10 short tons
Plan dimensions	
Operating	31.5 FT x 75 FT
Shipping	31.5 FT x 63.0 FT
Cargo space	13 FT x 60 FT
Speed	80 knots
Operating height	3 FT
Installed horsepower	3170

Comparative operational advantages with respect to fully skirted ACV:

Greater economy at extended distances

Greater operating speed

Longer range self deployment capability

Larger cargo space with greater load factor in multiple vehicular loads.

b.

Configuration	fully skirted
Load capacity	15 short tons
Plan dimensions	
Operating	20.5 FT x 41 FT
Shipping	20.5 FT x 41 FT
Cargo space dimensions	11 FT x 35 FT
Speed	40 knots
Operating height	3 FT
Installed horsepower	3420

Comparative operational advantages with respect to partially skirted peripheral jet ACV:

Greater load capacity in a smaller configuration

Improved overland capability because of smaller clearance dimensions

Improved transhipment transportability in existing and projected shipping

Greater economy of operation at short and intermediate distances.

Each of the above configurations of ACV lighters can be loaded to capacity with single-tiered containerized and/or palletized cargo. Each has cargo space adequate for loading appreciably all of the military vehicles falling within the weight classification of its respective load limitations.

B. RECOMMENDATIONS

In view of the potential increases in military capabilities obtainable at reasonable cost in the 10 ton capacity partially skirted air wall configuration and in the 15 ton capacity fully skirted configuration of ACV lighterage, it is recommended that:

1. Comprehensive preliminary design and analysis of both types of air cushion vehicles suggested by this analysis should be carried forward simultaneously until such time that the studies indicate one vehicle type to be clearly superior. Construction of the selected vehicle to serve as an experimental first generation operational vehicle should be accomplished. Intensive and comprehensive operational tests of the vehicle in realistic operational LOTS missions should then be accomplished to provide the data necessary for future design and formulation of sound military policy toward use of air cushion vehicles in LOTS operations.

   As an alternate approach, it may be highly desirable to proceed with a smaller payload machine, for example, say five tons. Significant savings in development funds and a shorter development time should result with only minor compromises in the attainment of the needed operational data.

2. Because of the economic sensitivity of ACV lighterage to structural weight, it is recommended that sufficient experimental tests and analytic studies be conducted to determine with reasonable exactness the structural loads that will be imposed by wave impact in both cushion borne and water borne rough water operations. Use of the above recommended vehicle for performance of the tests is considered desirable.

3. The potential benefits from use of flexible skirts on ACV lighterage makes obligatory the recommendation that substantial effort be devoted to experimental test and analysis of skirt element structural design and drag.

4. Further analysis of LOTS operations to include consideration of an ACV lighter family and a mix of ACV and other lighters to provide total system capability at minimum cost is recommended. Such analyses should include the operational data obtained with the ACV and other lighter types such as amphibious hydrofoil and amphibious planning hull craft which are currently under research. Additionally such analysis should include consideration of the effects of partial loss of the lighter force.

A listing of design criteria applicable to a first generation air cushion vehicle lighter is presented in the following section of this report.

(U) SECTION IX

FIRST GENERATION ACV LIGHTERAGE

DESIGN CONSIDERATIONS

A. GENERAL

The following design considerations are tentatively established as basic requirements for full realization of the potential of ACV lighterage in LOTS operations. The existing air cushion vehicle technology and the lack of operational testing and experience preclude an exactness of specification in many instances. Where criteria have been quantified, the values are predicated upon reasonable assumptions of those required to obtain safety of operation and a practical operational capability in a first generation vehicle. Provision of sufficient capability to permit a full range of operational testing is paramount. As design studies progress, areas will undoubtedly develope where additional research and experimental test can be productive in refining the design criteria that are quantified hereinafter.

B. CONFIGURATION

The analysis developed in this study produced two general configurations of ACV lighterage for more detailed consideration. Both were skirted types; the one was a partially skirted peripheral jet configuration while the second was a fully skirted plenum chamber type. The difference in length and application of the flexible skirt resulted in differences in optimum plan form dimensions, load capacities, operating speed and installed power. Military advantages accruing from either configuration are believed sufficient to warrant further developmental effort although the optimum length of skirt to be used in the ACV lighterage application is not precisely definable in view of the limited technical information developed to date.

The flexible skirt is undergoing development and test by this contractor and shows promise of early solution of the technical design and fabrication problems involved. However, this development has not progressed to the point where the question of the partial versus the full skirted application can be fully assessed. Accordingly, a

specific configuration has not been selected. The following design criteria are believed fully applicable to ACV lighterage in the 10 to 15 ton load capacity classification. The criteria set forth are believed of sufficient importance that they must be considered in developing a basic ACV lighterage layout and structural design.

C. PERFORMANCE CAPABILITIES

1. OPERATING HEIGHT

An operating height of 3.0 feet is considered necessary for first generation skirted or partially skirted air cushion vehicles for use in LOTS operations.

2. PAYLOAD

Design operating payload of from 10 to 15 short tons is required for transport of the major proportion of Army vehicular equipments and all dry cargoes.

3. SPEED

Overwater operating speeds of from 40 to 80 knots are desirable for economy of ACV lighterage in LOTS operations. The degree of skirting provided the ACV will, to a large measure, dictate the overwater cruise speed. Efficient operation inland at speeds as low as 15 knots is also important to achieving economical ACV lighterage operations.

4. MANEUVER

Lateral and longitudinal maneuver capability of .25 'g' during hover operation should be provided the first generation ACV lighter. Additionally, lateral maneuver capability of .25 'g' should be provided at the design cruise condition. Deceleration capabilities of .4 'g' to .5 'g' at forward cruise speed appear to be reasonable and readily available from provision of static longitudinal acceleration capabilities.

5. GRADE CAPABILITY

"Holding" capability on a 25 percent grade, both longitudinally and laterally, will be obtained at design gross weight by provision of the recommended .25 'g' maneuver capability. Additional capability to approximately 35 percent grade at a steady state speed of 5 knots can be obtained by operating at reduced heights. Steeper than 35 percent grades can be negotiated for moderate distances by trading off forward speed.

D. OPERATIONALLY INDUCED CRITERIA

1. CARGO SPACE

a. Provide a minimum cargo space 11 feet wide by 35 feet long in the 10 to 15 ton capacity lighters.

Provide additional cargo space as practicable if overload operation at reduced operating height is contemplated. Provide a clear height in the cargo compartment of 11 feet.

b. Provide for wheel and axle loading of the cargo compartment floor of 6000 pounds and 13000 pounds respectively.

c. Provide for cargo compartment floor loading of 500 pounds per square foot.

d. Provide structure against operationally induced vertical acceleration of 4 g.

e. Provide for cargo tie down restraint of:

4 g forward
1 g vertical
1 g lateral
1 g rearward

Utilize aircraft tie down principles and gear as practical.

f. Provide a replaceable buffer strip around the upper edge of the cargo compartment to protect against swaying cargo drafts being lowered into the lighter

g. Provide flooring structure to sustain vertical impact of 5 ton cargo drafts contacting the cargo compartment deck at a velocity of approximately 4 feet per second If cargo positioning gear is installed in the lighter it may prove necessary only to provide a limited area of highly stressed cargo deck the width of the lighter cargo space and twelve feet in length. Dunnage of normal types may be considered as a partial cargo floor buffer.

h. Provide full load capacity fuel tanks as a kit installation in the cargo compartment for the purpose of long range self deployment and to permit use of the lighter as a bulk fuel tanker.

i. Provide an integral ramp or treadways for roll-off unloading of vehicular cargo operating under its own power. Provide for wheel and axle loadings of 6,000 and 13,000 pounds, respectively and a ramp angle on level ground of not more than .15°.

j. Provide, if at all practicable, cargo positioning gear with a capacity of 10,500 pounds and vertical lift sufficient to handle standard Conex containers. This gear should have sufficient out reach from the lighter to permit transfer of a single container to a truck or.to the ground.

2. WAVE IMPACT

Provide structure sufficient to withstand wave impact when operating at normal cruising speed in a level attitude and with hard structure impinging at a level two feet below the wave crest. (Reference 16 indicates an 8 'g' loading at the bow, and dependent on bow shape and vehicle speed 30 psi to 50 psi bow plate loadings).

3. BUOYANT OPERATION

a. Provide compartmented buoyancy such that rupture of two adjacent compartments will not result in the loss of the lighter.

b. Provide integral fenders for protection of the lighter structure from impact damage while coming alongside and loading at the ship's side in a state 3 sea.

c. Provide towing bitts and cleats for securing mooring lines.

4. GROUND HANDLING

a. Provide ground handling gear with a static foot print pressure at designed gross weight of 15 pounds per square inch.

b. Provide limited rolling mobility on hard surface for the purpose of "walking" the lighter away from a self unloaded cargo and for towed mobility in connection with maintenance operations.

c. Provide base clearance when on ground handling gear of 24 inches above a flat surface.

d. Provide jacking points capable of supporting the operating empty weight of the lighter.

e. Provide sling hoisting points and a single point lifting sling for ship board loading and unloading.

f. Provide for tow bar attachment fore and aft.

E. PERSONNEL SAFETY REQUIREMENTS

1. SEAT BELTS

Provide safety belts at all crew members' stations. Shock mounted seats may be desirable for configurations employing forward positioned crew compartment.

2. SEATS

Provide for removable bucket seats with seat belts for capacity passenger load.

3. WALKWAYS

Provide railed cat walks at the sides of the lighter cargo compartment to accommodate troops and stevedores loading aboard the lighter via cargo nets suspended over a ship's side. Provide appropriately located ladders for descent into the cargo compartment.

4. SAFETY GUARDS

Provide adequate guards or screens at fan and propeller inlets for personnel safety and as a guard against foreign object ingestion.

5. SAFETY IN MOORING

Provide safe areas for handling mooring lines when coming

alongside a ship or in lieu thereof provide a remotely controlled automatic hook-up system.

6. HATCHES

Provide escape hatches from closed crew or passenger compartments.

F. ACV INDUCED ENVIRONMENTAL CRITERIA

1. SPRAY AND DUST

Provide spray and dust suppression to the extent required to permit adequate operator visibility. Note: peripheral skirting alleviates this problem.

2. INFRA RED SIGNATURE

Provide insulation for engine hot section. Provide for engine exhaust into cushion air under the vehicle.

3. NOISE SUPPRESSION

Provide noise suppression to the extent necessary to insure crew comfort and passenger tolerance. Use of low tip speed fans (approximately 700 feet per second or less) is recommended.

4. VIBRATION SUPPRESSION

Provide a dynamically stable vehicle with machinery and aerodynamically induced accelerations held to less than 0.15'g' in the frequency range of 0.2 to 5.0 cycles per second.

5. WAVE IMPACT ACCELERATIONS

Provide hull configuration to restrain wave impact accelerations to plus 4 'g' vertically and 4 'g' forward when striking the wave at not greater than two feet below its crest at rated operational cruising speed.

G. NAVIGATION AND COMMUNICATIONS

Provision of standard military navigation and communications equipment are implicit. Possible need is seen for radar navigation equipments and UHF-VHF communications equipment. Provision of any special equipments should, however, be based on results of experimental vehicle tests in realistic LOTS operations.

H. MAINTENANCE PROVISIONS

Provisions for ease of maintenance applicable to other vehicles are also desirable for the ACV. For example the use of standard parts and components, interchangeability of components, ease of access through maintenance doors, etc., are equally germane to the ACV. The environment and characteristics of the ACV lighter do, however, suggest emphasis on the following points.

1. VEHICLE WASH DOWN

Provide for ease of wash down and removal of salt spray deposits.

2. SIMULTANEOUS MAINTENANCE

Provide for simultaneous maintenance of vehicle components. The size of the ACV and distribution of its propulsion components will probably permit inspection and maintenance to be accomplished efficiently in a shorter period of time by a larger maintenance crew than is possible with many other vehicles. Proper advantage should be taken of this factor to reduce maintenance down time by provision of adequate access to components and elimination of all possible sequential maintenance operations.

3. FUELING

Single point pressure fueling should be provided to permit maximum vehicle utilization and safety in refueling operations.

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